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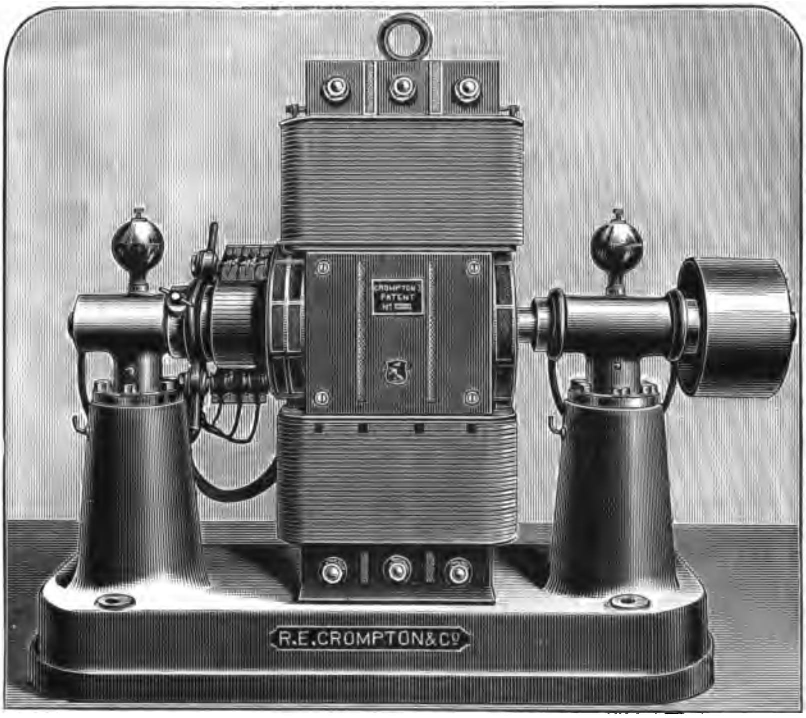

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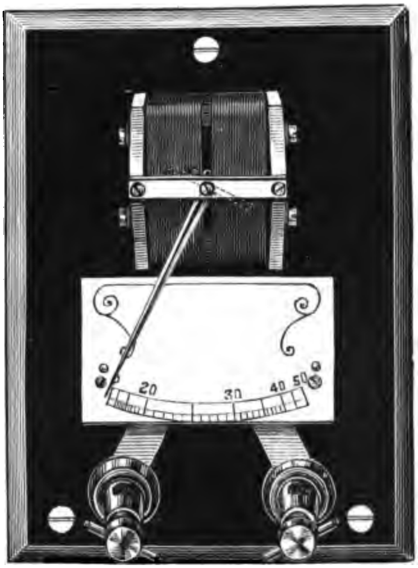

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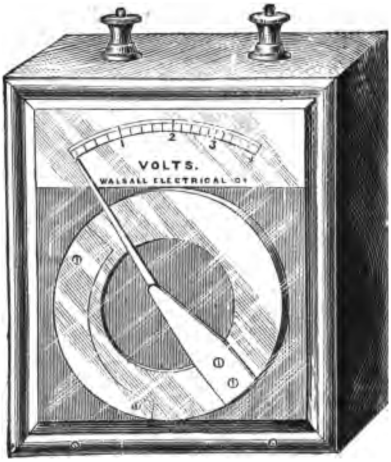

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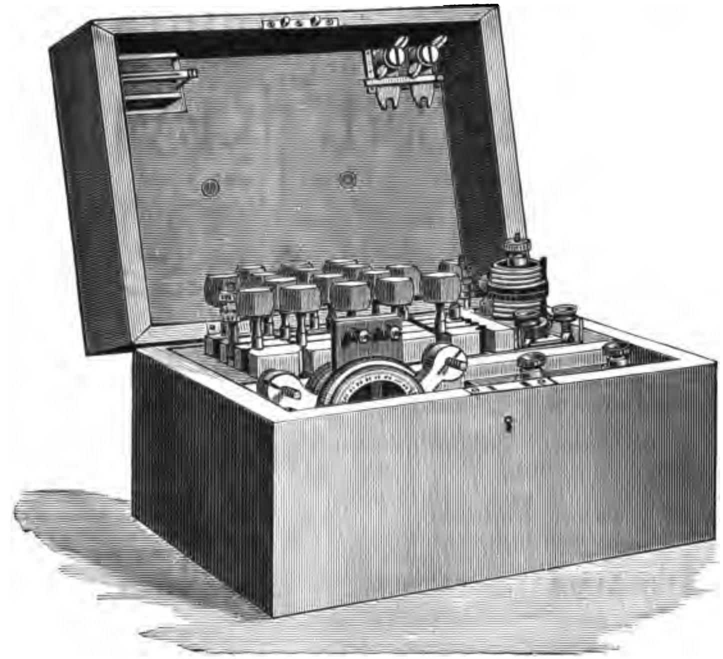

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PRACTICAL

ELECTRICAL MEASUREMENT.

(*55 ILLUSTRATIONS*).

BY

James
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PREFACE.

Many electrical engineers have felt the want of available information as to the various methods of testing and the use and calibration of the numerous instruments. The electrical student has abundant instructions as to the use of laboratory instruments, as they are fully described in text-books; and articles and papers have been written on standardising instruments for very exact measurements with elaborate apparatus.

The telegraph engineer's wants are already satisfied by Mr. Kempe's standard book on electrical testing, not to mention many other works.

Heavy electrical engineering has brought into use large currents which are out of the ken of telegraph engineers; strong magnetic fields; and, in fact, a set of conditions altogether different from those met with in the telegraph office, or in academic teaching.

In this book it is attempted to describe and discuss the various measurements necessary to the electrical engineer—that is to say, to write about electrical measurements in the workshop as opposed to mere laboratory practice. The different instruments in use are discussed somewhat critically, and their merits, and faults when they have any, pointed out. Such points as accuracy in ordinary use, portability or cheapness, are considered as of more importance than absolute accuracy under laboratory conditions. Long descriptions of things always to be found in text-books have been avoided; and the reader will be spared the discussion of the best ways of coupling cells, and the dissertation on shunts.

The writer has avoided using mathematical symbols, partly to make the book more readable, and partly with the hope of setting an example to others. The pedantic fashion of dragging mathematical symbols into all electrical literature, and the respect commanded by an analytical investigation, even on false data, often lead writers to mar work otherwise good, by getting out of their mathematical depths and writing nonsense to look learned.

The book is mainly a reprint of a series of articles in the *Electrical Review*. The articles have been carefully revised and partly re-written; and the writer has gratefully availed himself of suggestions in the correspondence columns of that journal.

There is no pretence to originality, as the space is mainly devoted to descriptions of instruments and their uses; but some novelty will, it is hoped, be found in many of the methods and arrangements described.

As many readers may know that the writer was connected with Messrs. Crompton & Co., he must state that he had nothing to do with their instruments, and must disclaim any credit that may be due to those who have designed, made, and calibrated them.

Acknowledgements are due to the Proprietors of the *Electrician*, *Industries*, and the *Electrical World*, and to the Editing Committee of the *Journal of the Society of Telegraph Engineers*, and to others, for kindly lending blocks.

CHELMSFORD, *November 15, 1888.*

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PRACTICAL ELECTRICAL MEASUREMENT

BY

J. SWINBURNE.

CHAPTER I.

RESISTANCE.

THE measurement of the resistances which have generally to be tested, such as from 1 to 100 ohms, by means of the Wheatstone bridge, need not be discussed, but a few words may be said about resistance boxes and bridges in common use. It is much to be regretted that some enterprising firm of electrical manufacturers does not take up the wholesale manufacture of such instruments as Wheatstone bridges, &c., as they are not at present made to suit the demand of the electrical engineer. Messrs. Woodhouse & Rawson are working in this direction, and it is to be hoped others will follow. The bridge is an instrument which can be made correct within a very small error, that is to say an error that is quite imperceptible in ordinary engineering work. Any slight error in the bridge is also very easily found out, as it can always be checked against itself. The result is that the only bridges available are expensive instruments, costing from £20 to £30, considerable trouble and expense are incurred in the first place to adjust the coils with perfect accuracy, and an elaborate but unnecessary finish is indulged in to do justice to it. A bridge costing two or three pounds, suitable for ordinary installation work cannot be obtained. It is by no means intended to depreciate accuracy :

an accurate instrument is better than an inaccurate one, other things being equal; but it would be absurd if a grocer could buy nothing cheaper than a chemical balance to weigh with, because scale makers found they were capable of very great accuracy and had plenty of room for unnecessary finish. Accurate bridges are required for such work as localising faults in telegraph lines, but rough resistance boxes right within say ¼ per cent., would be good enough for ordinary work. As it is, an installing engineer who would not scruple to dispense with a voltmeter and judge the electromotive force by the look of the lamps, searches for ground contacts with a forty guinea bridge in conjunction with one defective Leclanché cell and a pivotted detector which sticks.

In many cases that occur in practice resistances may be taken by passing a fairly large current through whatever is to be measured and taking the volts and amperes.

In measuring the resistance of such things as magnet coils, the battery key must be pressed and kept down a moment, otherwise the self induction of the coil will send the light spot off the scale.

If the galvanometer is near the dynamos, or in a place where the field varies while the resistance is being taken, considerable trouble will arise. The orthodox thing to do is to put an iron shield over the instrument. This cures the evil in text-books, but does not always work well in practice, perhaps because the coercitive force of the iron is too great to allow it to respond readily to the slight variations in the strength or direction of the magnetising force. The ordinary Thomson reflecting galvanometer is out of place in most workshops, and the d'Arsonval galvanometer, fig. 1, should be used. This consists of a little rectangular coil of wire suspended with each side in a very strong magnetic field. This is really an adaptation from the siphon recorder, and shows how completely Sir William Thomson's work seems to permeate Electrotechnics. In abandoning one of his instruments we adopt another. An instrument on this principle was, however, described by Varley in 1856. D'Arsonval's pattern is not much used in this country. It has the great advantage that it is not affected by slight changes in the external field. It has the drawback that it cannot be wound for very low resistances, as the circuit is made through the suspensions; but this does not concern us now. The d'Arsonval galvanometer is most perfectly dead-beat when its circuit is closed. A key that short circuits the coil when raised should therefore be used with it. For most purposes the instrument would probably be improved by having its wire wound on a small copper former, so that the copper circuit would act as a damper.

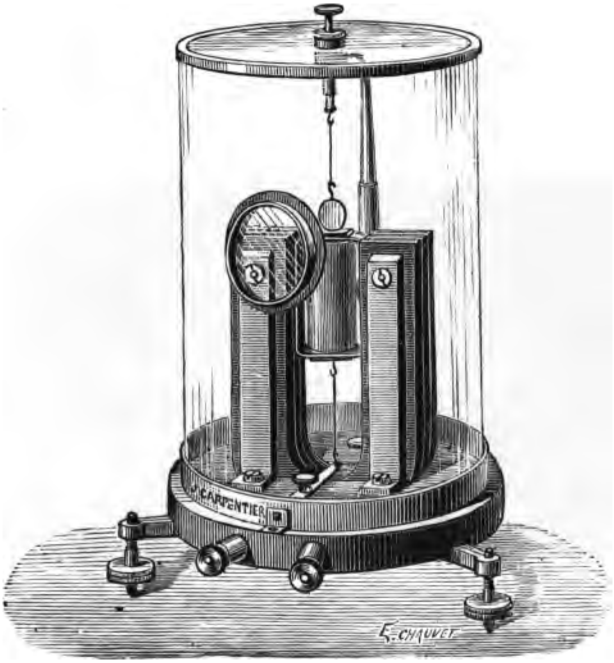


FIG. 1.

It is often needed to test very low resistances such as that of a short piece of thick cable, or of the armature of a dynamo machine. The methods generally given in text-books for measuring very low resistances are not suitable. The difficulty in measuring very low resistances arises from the impossibility of making good contacts. If it were attempted to measure the resistance of an armature of about one-hundredth of an ohm, the resistances to be taken would only be a small fraction of the resistance of the wires from the bridge to the armature, and the fall of potential where these wires join the commutator would introduce an error as large as the desired reading. The least dirt on one of the plugs of the bridge would also give rise to errors.

The following method is a modification of an arrangement for measuring very low resistances, which appears to be due to Heaviside, who published it in 1873. It is sometimes credited to Tait and to Kirchhoff. The current is passed through the cable, or whatever is to be measured, and through a very low standard resistance which can be adjusted, and the fall of potential is compared by means of a differential galvanometer. In the diagram, fig. 2, A is a standard resistance, which is a rod of German silver, of somewhat higher resistance than the sample of cable. The resistance of A has been carefully taken between the two marks, F and G, and is say, ·01 ohm. It will be explained how to make this bar presently. The bar, A, is graduated and divided up into 10ths, 100ths, &c. C is one coil of the galvanometer, which is of very low resistance. One wire, N, can be slid along A, so as to include any resistance less than ·01 ohm, B is the sample of cable, and D is the other coil of the galvanometer. The wires, H, I, are a foot or a yard apart, and L is a battery of cells (a storage cell is suitable) arranged to give a large current. M is the battery key, on pressing which a

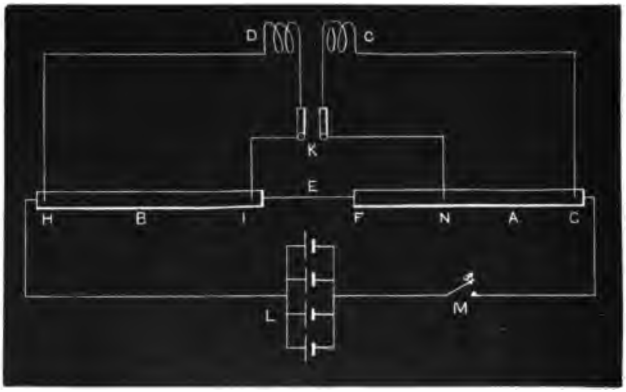


FIG. 2.

current is sent through A and B in series, and the double galvanometer key, K, is then pressed. N is then slid along A till the spot comes to zero. The fall of potential between G and N is then the same as between I and H, so the resistance of the cable per yard is read off along A. This measurement is not interfered with by any bad contacts between the wire E and B or A, or between the battery wires and A or B. Instead of having a sliding contact at N, the wires may be fixed and the galvanometer circuits may have adjustable plug resistances. This is the original form of the Heaviside or Kirchhoff arrangement. The sliding arrangement has the advantage of greater quickness in working and it saves calculation. If resistance boxes are put in series with the coils of the galvanometer the resistance of the coils must be taken into account in each measurement, as, if they are so small in comparison with the resistances in series with them that they may be neglected, the arrangement is no longer sensitive.

If B is the armature of the dynamo, the wires for the main current are clamped to the commutator sections, and the pilot wires from the galvanometer, or feelers, are clamped to the same sections. The feelers must on no account be attached to the main current wires, as that would include the bad contacts over which there is a fall of potential. Bad contacts between the feelers and the segments of the commutator do not matter, as their resistance is small in comparison with the resistance of the galvanometer. The galvanometer should be tested for leakage from one coil to the other, as well as to see if the resistance of the coils is the same. To see if the instrument is truly differential, it is coupled up with the coils in series, and electricity passed through. If the spot moves it is not accurately differential. If it is differential the coils should be coupled in parallel, and the instrument tried again. If there is no deflection the coil resistances are equal. For measuring resistances in the manner just described, it is enough that there is no deflection when the coils are in parallel, as in that case any error due to the resistance being wrong is exactly balanced by an error by which the instrument is not differential. If the galvanometer is wrong, artificial resistance must be put in series with one coil. To test for leaks, a terminal of a battery is put on each coil, so that if the other two ends of coils were connected both coils would deflect the needle the same way. If there is any deflection the coils leak one to the other. Leaks from coils to frame should also be tested for.

Sir W. Thomson's method is described in most text books. It may be adapted for use with the sliding standard. Fig. 3 is a diagram of Sir W. Thomson's method. This method was originally for measuring the resistance of bars which could be joined together as shown, so that the fall of potential between S′ and T′ can be neglected. G is an ordinary galvanometer, and A, P, R, C are resistances which are high in comparison with the resistance between S and S′ and between T′ and T. If this arrangement is used for measuring dynamo-armatures, the resistance between S′ and T′ at once becomes important, as it most likely includes a pair of leads from the test room to the armature shop; any errors due to this must therefore be eliminated. To do this P is made equal to R, and A to C. The galvanometer then comes to zero, when H = F, and one feeder is slid up or down the graduated bar till there is no deflection. It is not necessary for R to be equal to C and P to A, what is really wanted is that $\frac{P}{A}$ should be equal to $\frac{R}{C}$. The arrangement can be made to multiply or divide as the ordinary bridge does. Thus if R = 10 P, and C = 10 A, F will be equal to 10 H.

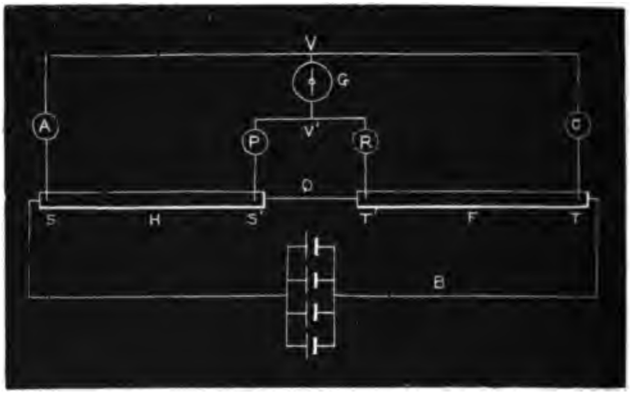


Fig. 3.

An ordinary Post Office bridge may be coupled up so as to compare two very low resistances by Thomson's method. In addition to the bridge and galvanometer a coil of insulated wire and a key are needed. The resistance of the coil is first measured in the ordinary way. The bridge is then coupled up as shown in fig. 4. The plug or strap that makes connection between Q and W is removed, and the galvanometer is inserted between the battery key, T and S. The measured coil, R, is inserted between S and G. The plugs are drawn between W and S so as to give a resistance equal to that of the coil, R, and the bridge proper has equal resistances drawn. N is then slid till the galvanometer is not deflected on pressing the key, T. By making R ten times or a tenth of the plug resistance, and altering the bridge to match, B can be compared with a tenth of or ten times A, and so on. Thomson's method admits of the use of a d'Arsonval galvanometer.

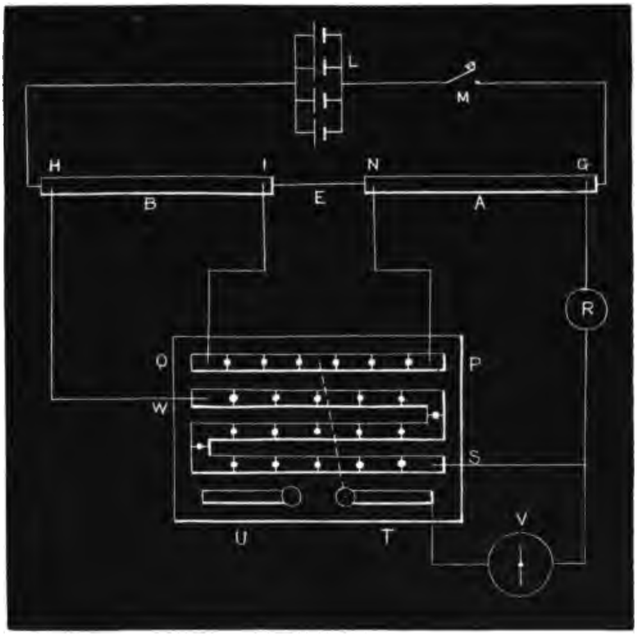


FIG. 4.

The standard rod, A, is got by first making a thick piece of wire one ohm between two marks on it. This is set up as in figure 2, and the resistance is inserted in the galvanometer coil that is in shunt to it, so that the resistance of the coil and resistance are ten times the resistance of the other coil. A much thicker rod is placed at B, and two marks are thus found including 0·1 ohm. This bar is then put in the place of A, and a new bar put as B, and marked to include 0·01 ohm. This bar is carefully checked along its length to make sure that the fall of potential is uniform; this is done by including short distances between the feeders, N and G, and balancing by putting H and I, close together. If it always takes the same distance between H and I, to balance B, it is right. It is then marked off into 100 or 1,000 divisions corresponding to $\frac{1}{10000}$ and $\frac{1}{100000}$ of an ohm. If the bar is uneven, it can be measured every here and there along its length by putting N and G back to the marks and altering the resistance in series with C. A number of marks can then be made on B, and the spaces between them can be divided off without any great error. If large currents are used to increase the sensitiveness of the arrangement, the various resistances must not be allowed to get hot, or corrections must be made for temperature.

Instead of dividing the scale to fit the resistance, it is often convenient to make the resistance fit a scale bought ready cut. To do this A is made small so that the resistance of, say, a metre is over, say, ·01 ohm. A shunt is then made and soldered on beyond the ends of the scale, and adjusted till the fall of potential over the metre is right. This plan is very valuable in null methods and cases where the pilot wires or feeders take no perceptible current. The bar must be made uniform before adjustment.

One or two forms of apparatus for measuring resistances have been brought out lately for the use of electrical engineers. Messrs. Elliot Brothers make a convenient little bridge and galvanometer combined for testing lightning conductors; this is also made with a set of silver chloride cells in a separate box, and the two boxes can be fastened together into one compact apparatus.

Messrs. Davies and Moynihan's combination plug and metre bridge, fig. 5 consists of an ordinary bridge on one side of the apparatus, and on the other a metre bridge is arranged for measuring low resistances. The galvanometer and cells are separate; the connections are the same whichever way the bridge is to be used, the necessary alterations being made in a very ingenious way by means of the galvanometer and battery keys. The keys, which are connected together, are simply turned to one side or the other, and are held there by a spring. The bridge is very compact, as it only measures 9½ inches by 4½ inches by 5½ inches deep, and the bridge, galvanometer, and cells pack into a slightly larger case. The weak point of such an arrangement is the metre bridge for low resistances. The error due to the resistance of the contacts themselves is too great to admit of accurate work. The metre bridge is also made up by itself, and forms a very compact instrument. This is a modification of the ordinary metre bridge, and is much the same in principle as the metre side of the combination plug and metre bridge, but it is larger, and the cylinder contains the coils belonging to the bridge. The outside of the instrument consists of a cylinder of ebonite, with a double-threaded screw cut in it. In one thread lies a piece of platinum silver wire,

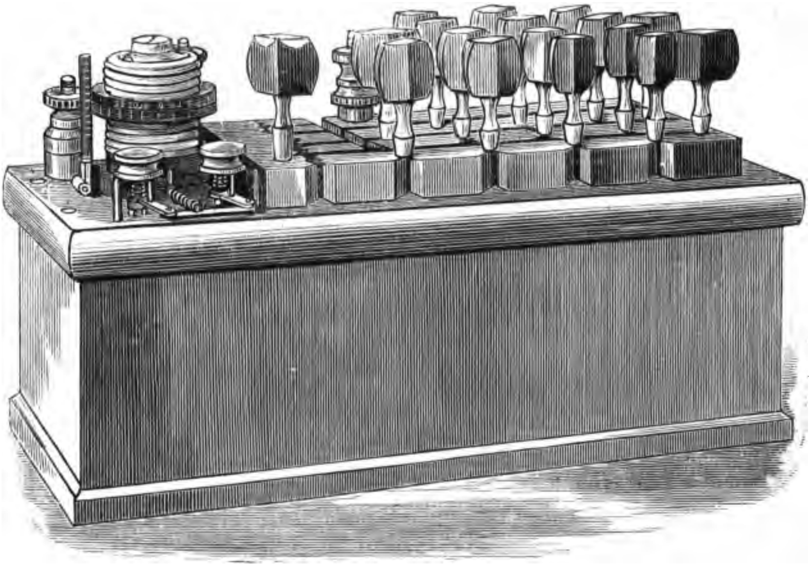


FIG. 5.

which forms the adjustable part of the metre bridge; in the other lies a wire connected with the galvanometer circuit. A ring is tapped to fit the double thread and screws up or down the outside, making contact between the galvanometer and the metre bridge wire. Inside there are coils forming the two sides of the bridge proper, plugs being used to alter the ratios. The coils are ·01, ·1, 1, and 10 ohms, and the instrument is supposed to measure down to ·0005. It need hardly be remarked that the contact and lead errors make it out of the question to measure such resistances as ·0005 ohms even approximately. This little bridge is, however, a very convenient and portable instrument. With its galvanometer it goes into a case 11½ inches by 6½ inches by 4¾ inches. It is made by Messrs. Woodhouse and Rawson.

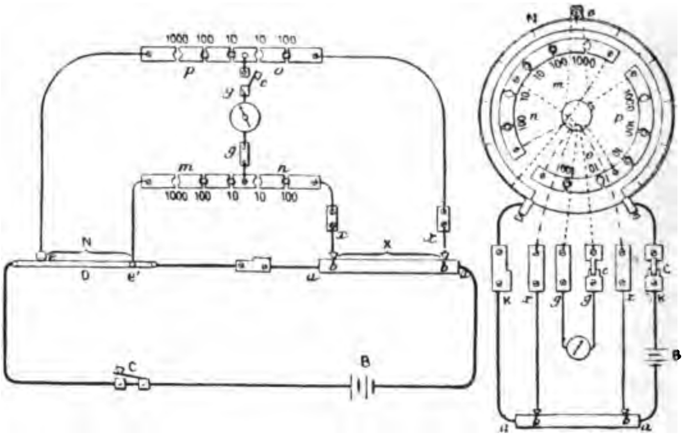


FIG. 6*a*.

Messrs. Siemens and Halske have lately brought out a portable form of Thomson's bridge for measuring low resistances. It is shown in figures, 6A & 6B.

The standard low resistance is a thick wire stretched round the instrument, and a movable contact is arranged so as to include more or less of the wire. Plug resistances are arranged so that the resistance can be multiplied or divided, so that the range of the instrument is very large. It is portable, and there is every reason to suppose it is accurate, as the contacts are not included in the resistance measured.

Sir W. Thomson's "mho-ohm" drum is an arrangement of resistances designed in such a way that they can be coupled up in series, so that their resistances are added, as in an ordinary bridge, or in parallel so that their conductivities can be added. The resistances are made up in the geometrical progression—1, 2, 4, 8, 16, &c., so that the calculations of conductivity are as easy as of resistances.

Messrs. Latimer Clark, Muirhead & Co. make a very convenient portable testing apparatus, fig. 7, designed by Mr. Blackburn. It consists of a small flat case containing a couple of chloride of silver cells and a bridge and galvanometer. The adjustable part of the bridge is worked by turning a circular plate with rubbing contacts, and the final adjustment is made by means of a wire stretched round it. This admits of very rapid adjustment, a point of great practical importance.

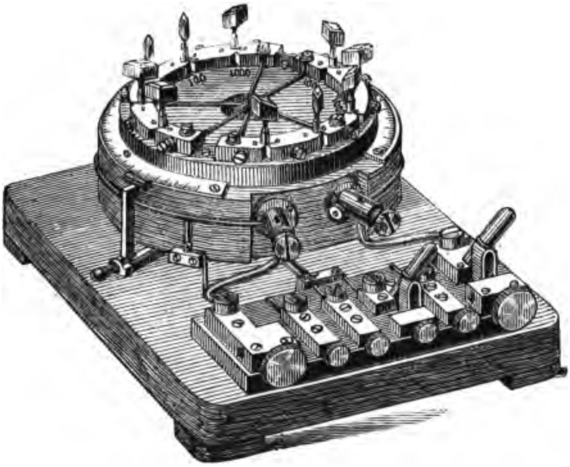


FIG. 6*b*.

One of the neatest portable arrangements is Cardew's lightning conductor bridge. It is not to be used where great accuracy is required, but for ordinary work, if only a small range is needed its portability and cheapness, and its readiness of adjustment recommend it. It is made by Messrs. Woodhouse & Rawson. It consists simply of a single wire stretched round the outside of a disc, in a loop, with a radial arm which makes contact

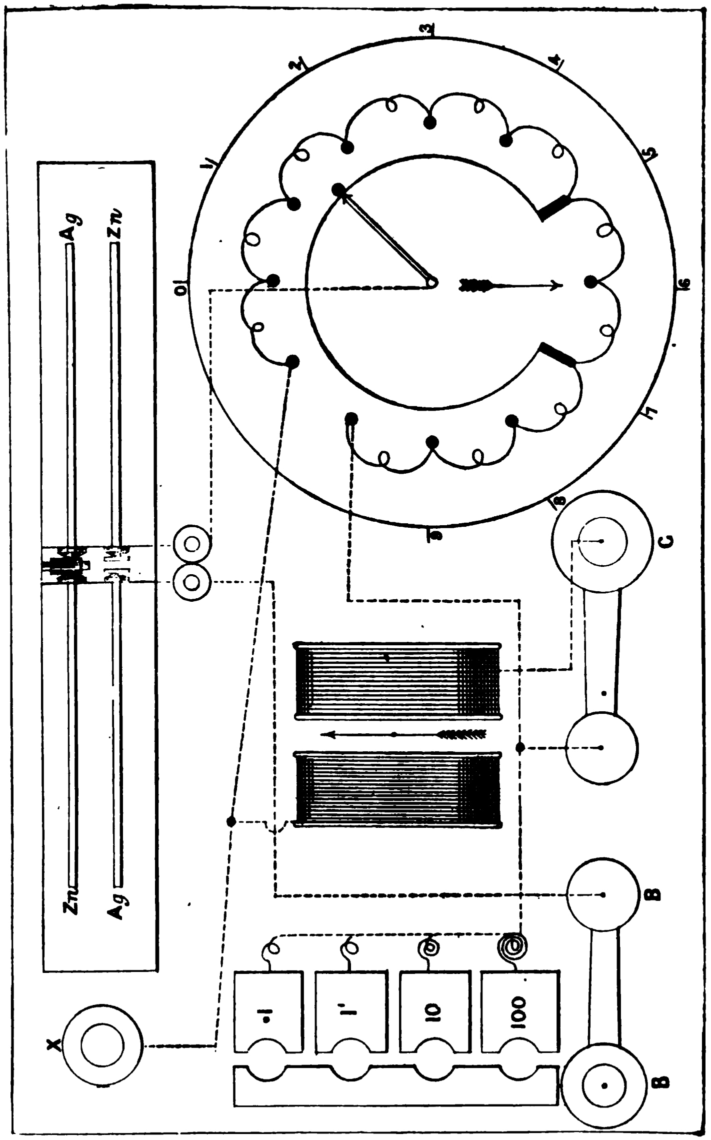


FIG. 7.

with one side of the loop. Terminals are supplied. Fig. 8 is a diagram of the bridge. The battery is connected to c and z.

Tracing the circuit from C it divides at D, from D to F forms one side of the bridge, and the galvanometer connection, G, is attached to F, and that part of the circuit goes on through the resistance, F H, then to Z. On the other side the circuit is from D to K, the galvanometer contact being slid along, and the resistance to be measured is put between E and L. The beauty of Cardew's arrangement is, that it is direct reading, and it will be discussed at some length, because it provides a very simple way of making up a direct reading bridge. If fig. 8 is expanded into the conventional form, it will be found to be a Kirchhoff bridge, as shown in fig. 9. The lettering is here the same as in fig. 8. In order that the instrument shall be direct reading, it is only necessary that M D : M K : : D F : F H ; M K can then be graduated

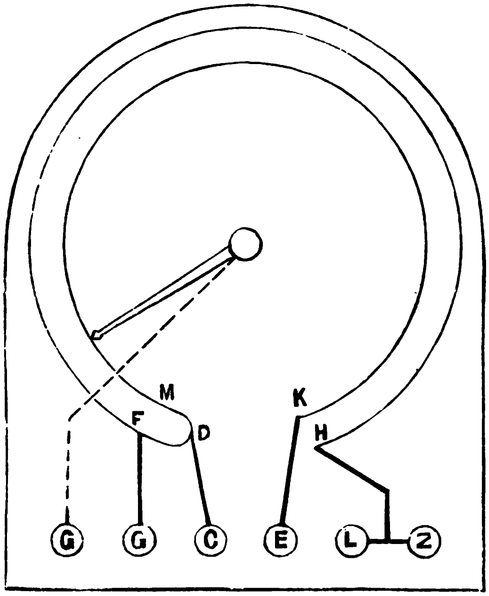


FIG. 8.

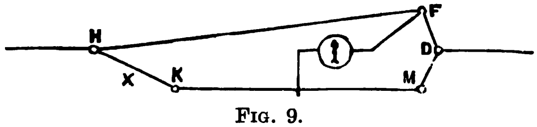


FIG. 9.

to read directly. Thus, suppose D F = ·2 and H F = 2 and M D = ·3 and M K 3 ohms, it is evident that when X = 0 the galvanometer contact is at M. When the contact is at K, the resistance K M + M D = 3·3 ohms, so X must be 33 ohms, as the other sides of the lozenge are as 1 to 10. K is therefore marked 33, and K M is divided into 33 equal parts.

The same arrangement may be very convenient for making up a simple bridge on an emergency, or for amateurs. Cardew's arrangement is not so good when stretched out straight, but is easy to make. An evenly divided scale divided into, say, 1,000 parts, is mounted as shown in fig. 10. A uniform wire is stretched over it from the binding screw, E to N, returning by D and F to the other binding screw, H. The calibration of this bridge is easy if another bridge is at hand, or if the scale is not bought ready cut, but can be divided up after the bridge is made. If the scale is bought ready divided and another bridge is not at hand, the bridge can be calibrated from any known resistance that may be obtainable. As the last method demands a tedious process of double adjustment it need not be described. Take first the case that another bridge is at hand to calibrate from, and the scale is already divided as shown.

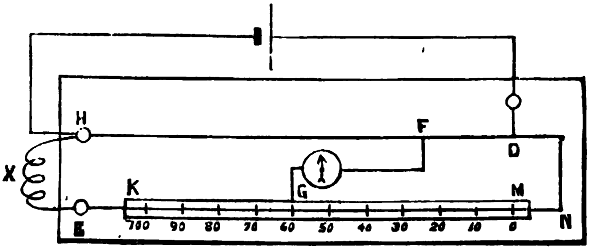


FIG. 10.

The points E, K, M and H are fixed because they are determined by the design of the apparatus. The problem is to find the points, F and D, so that the bridge will read proportionally from M to K and will read in ohms or tenths or hundredths. Suppose it is wanted to read 10 ohms when G is at K, or the 100 mark. The resistances of M K and M E are taken so as to find what number on the scale would be at E if the scale were continued. Call this number 110 for example. Then as the galvanometer must not be deflected when G is at M, E M : M D : : H F : F D ; and if G were at E, where the 110 mark would come, the galvanometer should not be deflected if $x = 11$ ohms. Therefore 11 : E M + M D : : H F : F D. From these two equations the positions of F and D are at once determined and measured off. If it is now wanted to make the bridge read from 0 to 100 ohms, two new points are found by similar equations for F and D. In an ordinary bridge the readings are multiplied or divided by altering one side of the bridge only, but in this form both F and D must be altered.

Take the second case. Imagine the scale is not yet marked off, and no bridge is at hand; but one coil of known resistance is at hand. Suppose, for example, it is a piece of German silver wire of 7 ohms. The scale is divided very roughly by eye into 10 parts, leaving a little spare room at each end. The 7 ohm coil is put between H and E and a pair of thick wires are also clamped to H and E and arranged so that their ends can be dipped into a mercury cup so that there is practically no resistance between H and E. Of course, it is assumed that the 7 ohm coil has a pair of thick copper wires soldered on, so that errors are not caused by clamping slightly more or less of the wire in H and E. The battery connection, D, is made temporarily at a point selected at random, and the galvanometer slider, G, is put at 0 or M. The other galvanometer wire, F, is then slid till there is no deflection. We have then one of the infinite number of pairs of positions of F and D that gives proportional readings. The mercury connection is then opened and the slider moved along the scale till there is no deflection. If G goes off the end of the scale before the galvanometer comes to zero, or if it is too near that end of the scale, M D has been taken too long, and a new position must be taken nearer M. If G comes too near M, M D has been taken too short. A new position for D must be taken, and a new position for F must be found.

This process must be repeated till there is no deflection with the 7 ohms in when the slider, G, is close to, or at the rough 70 mark. The connections at F and D should then be soldered, and the whole left to cool, as the wires will be warmed by the soldering and by use, and the coil of 7 ohms may also have been heated and may have a different temperature coefficient. When the normal temperature is reached the mercury contact is made, and the point, M, very carefully found, and marked 0. The point 70 is then found with equal care, and the scale is then divided up into 100 or 1,000 equal parts. For high or low readings the points for the battery and galvanometer connections can only be found by double adjustment.

It is needless to say that it is here assumed that the wire is uniform in resistance between K and M. If the wire is not uniform, it can only be checked from a standard resistance box, 1, 2, 3 ohms, and so on, being inserted at X, the points 10, 20, &c., being thus determined before the scale is cut. The distances between 20 and 30, and so on, can be subdivided into equal parts without appreciable inaccuracy. Platinoid is the best wire, as it alters little with variations of temperature, and is cheap.

Such a bridge as this is not capable of very great accuracy, but is good enough for rough work. For instance, if the scale is 25 inches long, a quarter of an inch stands for one per cent. at the end of the scale, and the bridge can be worked within half per cent. if the wire is fairly uniform.

There is no reason why the wire should not be coiled round a double threaded screw as in Davies and Moynihan's metre bridge; the bridge would then read directly. Cardew's lightning conductor bridge is, of course, only designed for very low resistances, but it might thus be made a fairly good long range instrument, giving direct readings and great rapidity and convenience of use.

Another point of no little importance in workshop bridges made this way, is that errors due to dirty plugs, or bad sliding contacts, do not come in, as the only sliding contact is in the galvanometer circuit where a variable resistance does not matter.

It is sometimes necessary to test resistances of such things as incandescent lamps or arc lamps while running. This can always be done by measuring the volts and ampères, but it involves a calculation, and it is best to measure the resistance direct by means of an ohmmeter. This instrument was invented by Professors Ayrton and Perry. In principle, the ohmmeter consists of two coils at right angles to each other, with a small needle at the point of intersection of the axes. One of the coils is in series with the part of the circuit whose resistance is to be measured, and the other, which is of comparatively high resistance, is in shunt. If the coils are large and the needle short, the instrument will follow the tangent law, and the readings taken may be as in a tangent or skew tangent instrument, according to the angle of the axes of the coils. There is a slight error; this occurs, because, if the shunt coil is in shunt to the resistance only, the current taken by it also goes through the series coil; and if the shunt coil is in shunt to both the resistance and the series coil, the current through it depends not only on the resistance to be measured, but is also affected by the fall of potential due to the series coil. As this error is only theoretical, it does not matter. In practice it is so easy to calibrate an ohmmeter by direct comparison with a resistance box, that it is unnecessary to assume any laws. An ohmmeter made to follow the tangent law has another disadvantage; the coils must be far away from the needle, and so their fields are weak, and the earth's field is commensurate with them, and causes errors. In a tangent galvanometer arranged as a voltmeter or ammeter, the earth's field does not matter if it is constant, because the controlling magnets and the earth's field together form a field of constant intensity with which the field due to the deflecting coil is compared. But in an ohmmeter the variable field is not compared with a constant field, but with another variable field, so that the introduction of a constant field gives rise to errors. It is therefore advisable to make the fields due to the coils as strong as possible, so that the earth's field is very weak in comparison. In their ohmmeter Professors Ayrton and Perry seem to have paid particular attention to making the instrument read proportionally. This seems to be a weakness on their part. If it is as easy to make the instrument read proportionally as any other way, of course it may be as well to do so; but in general some other advantage, such as strength of field or sensitiveness, must be sacrificed. It is strange that so many physicists have taken so much trouble to design electrical measuring instruments to read proportionally. An instrument that follows a simple law seems to have a charm which cannot be resisted, and when it is impossible to make it follow a simple law, an attempt is made to make it look as if it did. These remarks do not refer in particular to Professors Ayrton and

Perry's ohmmeter, but to about half the instruments that have been brought before the public from time to time. Most instruments are only wanted to read through a small part of their ranges, and then the readings most used should be spread out as much as possible. Thus, an installation of 100 volt lamps should be provided with a voltmeter which goes over nearly its whole scale—between 90 and 110 volts. This, of course, does not apply to the ohmmeter, as it may be wanted for arc or incandescent lamps, or other purposes, and must, therefore, have as large a range as possible. Theoretically, the best graduation would be that in which the reading is taken within the same percentage throughout the scale with equal ease—that is to say, a logarithmic scale;—but no one would think of trying to design an instrument that would read with a logarithmic scale. Perhaps the object of making instruments with even divisions was to save expense in dials. If so, it is not worth while, as if a number of instruments are made exactly of the same dimensions, the scales will all be alike, and may still be engraved wholesale. But the practice of making the dials in this way cannot be too strongly condemned; every instrument pretending to accuracy should have its dial specially graduated, or should be carefully calibrated throughout its scale. It by no means follows that the instruments with printed scales are wrong, as they may be made in large numbers so nearly identical in dimensions, that the scales are sensibly alike. Thus, Sir William Thomson's "graded galvanometers" and the Ayrton and Perry volt and ammeters have printed scales which is not in the least against them. But when an instrument has its scale divided off into equal divisions, it must be regarded with suspicion. An ohmmeter, for instance, with even divisions, may be nearly right, and if made under the auspices of Professors Ayrton and Perry, is probably very nearly right; but it cannot be quite right, for there is no way of making an ohmmeter that reads proportionally theoretically. It can only be made to do so approximately by altering the coils about till something more or less like an evenly-divided scale is obtained.

The writer has made ohmmeters on the same principle as the skew tangent galvanometer for incandescent lamp work, but the fields are too weak for ordinary use.

Fig. 11 is a diagram of Mr. Evershed's ohmmeter ; the current coils are wound outside, and the shunt or pressure coil is globular in form so as to fit inside. It is placed at an angle of 45° so as to give a long scale. The shunt coil is wound with German silver or platinoid wire, and is put inside because, as the wire is of higher specific resistance, the necessary strength of fields can thus be obtained with the least waste of power. Inside the shunt coil a hard steel needle is suspended by a silk fibre. A second needle is hung outside the coils so that the instrument is astatic, thus eliminating the error due to the earth's field, a point which is of considerable importance. The instrument has a wide range, as its lowest good reading is about one-tenth of its highest. The range is increased by inserting resistance in series with the shunt coil. The instrument is graduated by experiment.

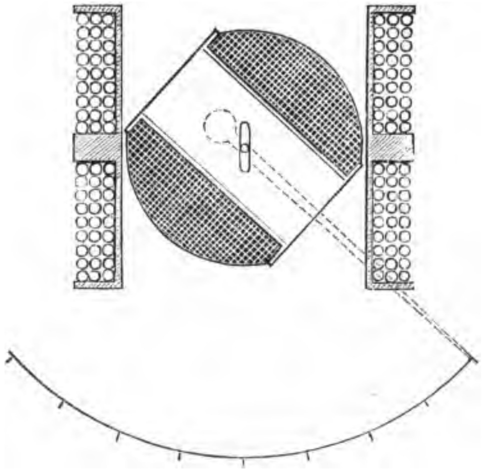


Fig. 11.

An ohmmeter should always be tested carefully to see if it is accurate before it is assumed to be correct. An ordinary bridge is not generally suitable, as it will not stand the current necessary. A piece of thick wire should be measured in the ordinary way, and the resistance should then be taken with an ohmmeter. Care must be taken that the wire has not time to get hot. The same resistance should be taken with a large current and a small one.

The errors to be looked for in an ohmmeter are, errors due to careless calibration, to heating and consequent rise of resistance of the shunt coil, to the earth's field, and to the alteration of the needle due to its being in a strong field. The first has already been discussed; the second can be avoided by having a key in the shunt circuit so that the coil has not time to heat, as it is not likely that continuous readings of resistance are wanted. The earth's field errors can be avoided by making the ohmmeter astatic, or by neutralising the earth's field by a controlling magnet, or by bringing the instrument into such a position that the needle is in the magnetic meridian when the reading is taken. The error due to the alteration of the needle's magnetisation can only occur when the needle is long, so that different parts of it are in resultant fields of different directions. If the magnetisation of the needle remains constant, the position will be the same whatever the absolute strength of the fields, and will depend only on the relative strengths, or the direction of the resultant fields in which it lies; but if its magnetisation alters unevenly when the resultant fields are altered in strength but kept the same in direction, the instrument will not be independent of the power spent in the resistance measured, as any part of the needle more strongly magnetised will have more than its proper influence in determining the direction of the needle. Broad needles are sometimes apt to get magnetised obliquely; this can be known by their not coming to zero when the key is up and the current passing.

The testing of leaks and insulation in installations may be taken under the head of measurement of resistances.

If there is a leak from either main to earth, represented by a convenient gas or water pipe, the first thing to suspect is the dynamo itself. A leak in the dynamo will most probably be from the field magnet wire to the frame of the machine. It is generally of no use to test for leaks with one or two Leclanché cells; a leak should be sought with the full E.M.F. of the installation on it. The dynamo may, if not series wound, be uncoupled from the main leads, and a detector should give no deflection, or if the machine is new, perhaps a slight one, with the fine wire coil between the frame of the machine, and the terminals. Though they should certainly not do so, makers occasionally send off machines with the magnet coils slightly damp. The coils generally dry themselves in time, but the practice is bad.

The next probable source of leakage is secondary batteries. These can be tested by disconnecting both ends and trying each end to earth with a detector. The thoughtless mistake of only disconnecting one end is often made in testing for leaks.

The only way to localise a leak in the mains or lamps is to disconnect both ends of each branch and test to earth with the electromotive force of the dynamo. Localising a leak in a parallel installation is a matter that often requires considerable ingenuity, and no very general methods can be given. Instead of using the dynamo itself to give the desired electromotive force for testing, it is a good plan to have a battery of little secondary cells, which may be made of lead wire and test tubes. Fifty little cells are just as portable as a Leclanché. A box 3 inches by four inches will hold 48. The test tubes should be about half full of acid, and should on the top of this have an inch or so of thick oil that will not splash out easily. In testing with cells, or any other E.M.F., the free detector terminal must be connected to the lead to be tested, and the other free terminal to earth; otherwise a ground leak in the dynamo or cells will interfere with the test.

When it is wanted to test the resistance of a leak it is a good plan to use a voltmeter of known resistance instead of a detector. This is, of course, only useful where the resistance of the leak is comparable with that of the voltmeter. Thus if a voltmeter is of 1,000 ohms resistance, and reads 100 volts when connected to the cells or dynamo direct, and reads 20 when put in series with the leak, the resistance of the leak is 4,000 ohms; for

$$\frac{\text{Direct reading}}{\text{Leak reading}} = \frac{\text{Resistance of leak and voltmeter.}}{\text{Resistance of voltmeter.}}$$

A very high resistance can also be measured by putting it in series with a galvanometer and noting the deflection. Artificial resistance is then inserted instead until the same deflection is got. If necessary the galvanometer may be shunted, as it is unlikely that a very high resistance box is at hand.

Messrs. Woodhouse & Rawson supply a very compact little astatic galvanometer with a megohm in the base. The reading is then taken according to the deflection. Of course such a method is very inaccurate, as the deflection is not really proportional to the current in the galvanometer. It would be better to vary the number of cells in use so as to work with the same deflection. A carbon megohm is also probably little suited for working with 100 volts or so. No doubt it is intended for one or two cells, but as a leak falls enormously in resistance when it has a high E.M.F. on it this method is generally inapplicable. This little galvanometer is otherwise a most convenient instrument. It has a silk suspension so arranged than it can be replaced in about a minute without the necessity of taking the instrument to pieces at all. The same firm also supplies a well made Thomson reflecting galvanometer for use with bridges, shewn in fig. 12.

Leaks in a series or arc installation may be easily localised by taking the E.M.F. between each of the terminals and the earth. Of course, as the E.M.F. on each lamp varies this is not quite accurate, but as the leaks often occur at a lamp, it easily tells which lamp is wrong. An electrometer is generally used for this purpose. More will be said on this point under the head of voltmeters.

For testing leaks with alternating currents a telephone, or one of Prof. Fleming's galvanometers may be used, as an ordinary galvanometer will not do.

Alternating currents demand such special consideration that they will be discussed by themselves.

Before leaving the subject of resistance the reader must be reminded that there are two ohms in use, the B.A. and the so-called "legal" ohm. Most bridges are made to the B.A. ohm; but it has, by recent careful determinations, been found to be less than the theoretical value. This was a matter of little or no practical importance, as in all calculations a coefficient comes in, and one coefficient is as easy to use as another. The B.A. Committee has now, most unadvisedly, recommended the adoption of the "legal" ohm, and the result is considerable confusion. In 1873 Maxwell wrote, "If more accurate researches should prove that the ohm, as constructed from the British Association's material standards, is not really represented by this velocity, electricians would not alter their standards, but would apply a correction. In the same way the metre is professedly one ten-millionth of a certain quadrantal arc, but though this is found not to be exactly true, the length of the metre has not been altered, but the dimensions of the earth are expressed by a less simple number." It would be advisable for a committee of cable, telegraph and electric light engineers to consider whether the "legal" ohm should be taken

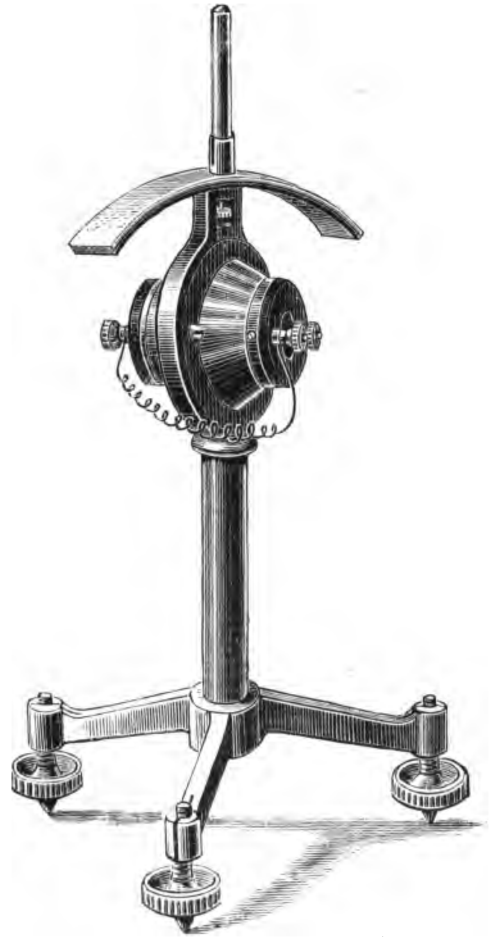


FIG. 12.

up or not. The old B.A. ohm is ·9867 of the new or "legal" ohm. A B.A. bridge can be patched up to measure in "legal" ohms by altering one side of the bridge, that is by replacing three or four of the coils. This is at best patchwork.

It need hardly be remarked that there is nothing legal about the "legal" ohm.

CHAPTER II.

VOLTMETERS AND AMMETERS.

Voltmeters and ammeters are so often the same instruments wound with different wire, that they will be discussed together. For the sake of simplicity they will be divided into groups, according to their principles of construction.

Permanent Magnet Instruments.

A very strong prejudice exists against the use of permanent magnets in measuring instruments. This prejudice is really unfounded, as a permanent magnet, if properly made in the first place, is constant enough for ordinary purposes, as it does not vary perceptibly from year to year, and the error due to its change is insignificant in comparison with the errors that are to be met with in many of the instruments now in the market.

Several physicists have carefully studied the "decay" of permanent magnets. A newly-made magnet, especially if strongly magnetised, loses its magnetism quickly at first, and then more and more slowly, till finally it remains practically constant. If it is not magnetised strongly to begin with, and is made of very hard steel, it is practically permanent from the beginning. Probably the chief reason why permanent magnets are not more generally used is, that as they cannot be patented; each maker prefers to push something else that can, and does so at the expense of permanent magnets and spring instruments.

The tangent is the best known form of the permanent magnet instrument. Sir W. Thomson's well-known "graded" galvanometers are tangent instruments, in which the needle and controlling magnet can be moved nearer or further away from the deflecting coil. The needles consist of four little bars of hard steel. These are attached to an aluminium cap like that used in Sir W. Thomson's mariner's compass. The index is formed of two pieces of thin aluminium, with their ends meeting to form the point of the index. The index is seen edgeways on looking down, and the aluminium is so thin that the instrument can be easily read. The scale is of paper, stuck to a piece of plate looking-glass. The controlling magnet is a semi-circular piece of bar steel arranged as a hoop over the needle. One end can be adjusted by a screw if the needle does not come to zero. The needle is enclosed in a three-cornered box, on which the controlling magnet also rests. This box rests on a short board of hard wood, and slides to and fro, being guided by a groove, in which two legs rest. The wooden slide is graduated according to the field produced at different distances from the coil. In a voltmeter the coil is of high resistance—that is to say, an instrument that will read up to 100 volts has a resistance of about 8,000 ohms. It has a ring of circular section; probably the object of this shape is to get the strongest field with the least waste of power, and the least deviation from the tangent law. The ammeter is the same as the voltmeter, except that it has a smaller coil of copper strip. A length of twin cable, with suitable clips, is supplied with each instrument.

As these are expensive instruments, and should be correspondingly accurate, they must be criticised somewhat exactingly. The writer had two for testing incandescent lamps. In these the paper scales were not quite accurate; in fact, the scales cannot be made accurate both for reading when the needle is right in the coil and when it is at the far end of the wooden platform, as the field due to the coil is not equally nearly uniform at different distances from the coil. The marks on the wooden base are so arranged that the magnet-box cannot be accurately adjusted to them, as there is a groove along the middle of the wooden platform, and the front of the magnet-box is slightly raised, and is, moreover, curved. The best plan is to fasten a piece of thin sheet brass to the front of the box, so as to touch the wooden slide. The slide can then be marked again, and places found where the instrument reads directly in volts and ampères. Of course this really means recalibrating the instrument; but that is a small matter. The resistance of the voltmeter coil was either marked wrong to begin with in the instrument used by the writer, which is unlikely, or it had fallen. The voltmeter was supposed to be graduated in Rayleigh volts, but the resistance was correct in B. A. ohms. It is most probable that the resistance of fine wire coils in all voltmeters gradually falls, and that it was a mere chance that the reading came right in B. A. ohms. The controlling magnets were not permanent, being apparently too strongly magnetised. The writer demagnetised them and magnetised them again more feebly, and after a little they were practically constant. The magnets are not fixed on, and are apt to be knocked off or dropped. In use they must be tied on, and it is needless to say that if the magnet is dropped or knocked about the instrument must be calibrated again. When readings for very wide ranges are needed, the graded galvanometers are very useful. When readings have to be taken all day, as in incandescent lamp testing, they are extremely valuable, as the resistance of the coils is so high, that the voltmeter does not read much too low on account of the wire heating, and the ammeter is of no perceptible resistance, so that the voltmeter may be put in shunt to it and the lamp.

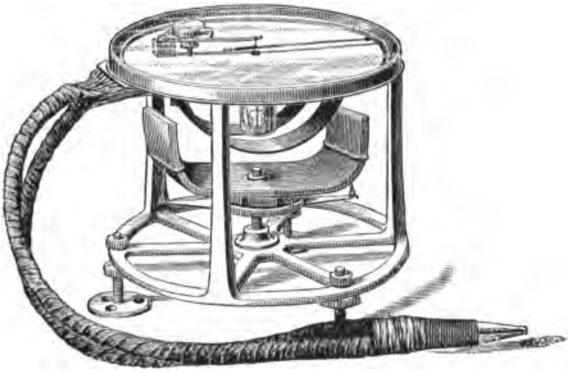


FIG. 13.

Sir W. Thomson's "lamp counter" is shown in Fig. 13. This is a permanent magnet ammeter. The controlling magnet is "aged" as much as possible by subjecting it to rough usage and to heating in boiling water and cooling. It is thus made practically permanent. The magnet can be raised or lowered to allow for adjustment if calibration should be ever necessary.

The most convenient form of tangent galvanometer is the skew instrument, in which the controlling field is not at right angles to the deflecting field. The controlling magnet may be placed at about 45° or 60° from its usual position. The advantage of this disposition is, that the scale is spread out in the middle where most of the readings are taken. The scales for such instruments can easily be drawn or marked off geometrically; but it will generally be found that an instrument does not follow the tangent law throughout its scale, and is about 1 per cent. out at the high readings. After an instrument is made, three or four points should be carefully determined, and the intermediate points can be found by dividing the distance between the known points according to the tangent law. The error will be then quite imperceptible. The great drawback of all instruments that follow the tangent law, even approximately, is that the controlling and deflecting fields must be comparatively weak, and the instrument cannot be used in the neighbourhood of dynamos, or near wires carrying large currents. The troubles arising from dynamo fields have been greatly exaggerated; it would be of no advantage to be able to put a voltmeter on the field magnets of a dynamo and take a reading, but an instrument should be unaffected by a dynamo ten or twenty feet off.

Fig. 14 shows an instrument designed by the writer. It is a permanent magnet galvanometer with the controlling magnet in parallel to the plane of the coil. This skew tangent galvanometer has a very convenient scale, as it can be made so as to be very sensitive at the middle of its range. The tangent law is not really depended on, as it is easier to calibrate the instrument throughout the scale than to calculate the departure from the tangent law. The controlling magnet is arranged so that it can be raised or lowered for calibration, and it can be turned so as to lie parallel to the plane of the coil so that it can be seen whether the index is attached to the needle at the correct angle. In the instrument shown in the woodcut, the needle is supported on an iridium point. A silk suspension may be used instead, as it is preferable if the instrument is not to be often moved about.

This instrument can also be made with the coil closer to the needle, so that the instrument takes exceedingly little power to work it. This is a matter of some importance in incandescent lamp work. For measuring very large currents it is generally best not to pass the whole through the instrument, but to arrange the ammeter as a shunt to the resistance. This saves the trouble of dealing with very large leads. When there are several circuits on a switch a measured resistance may be inserted in each, and couplings arranged so that the ammeter may be put in shunt to any of the resistances.

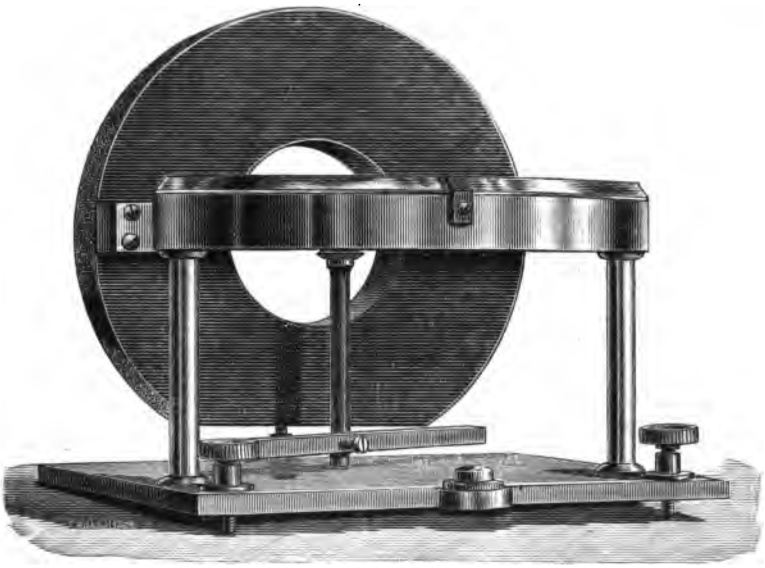


FIG. 14.

Mr. Crompton sometimes uses a reflecting d'Arsonval galvanometer for this purpose; but that cannot be recommended, as a reflecting instrument is not suitable for station work, and it cannot be assumed that the springs do not vary. Probably an instrument of the d'Arsonval industrial type would be better, as it is direct reading.

In 1881 to 1882 M. Marcel Deprez and Professors Ayrton and Perry seem to have hit on the same idea—viz., using permanent magnets to give the controlling field, and making the controlling field very strong, so that the instrument should not be affected by a neighbouring dynamo. The Ayrton and Perry permanent magnet instruments are too well known to demand description here. These instruments had some very serious faults; the inventors made the controlling field so very strong, and left so little room for the wire of the deflecting coil, that the deflecting coil got hot very soon, which, in the case of the voltmeters at least, interfered with the accuracy of the readings. The magnets also became weaker with age. Prof. Ayrton says this was due to the keeper, which, instead of preserving the magnetism, as is commonly supposed, weakens the magnets very quickly. In the later permanent instruments they have done away with the keepers. The early forms did not read directly, but were graduated in degrees, a constant being given with each instrument. The modern instruments are direct reading, but both early and later instruments are supposed to read proportionally, the pole pieces being filed into a particular shape, which is supposed to effect this. It is needless to say that it is impossible to make such instruments read proportionally with any accuracy, and they would be better if the fields were weaker, and if there were more room for the deflecting coils. The scales are short, and so readings cannot be taken with very great accuracy; but the instruments have some important advantages in being dead-beat, portable, and useful close to a dynamo. The early forms were all made by Messrs. Paterson and Cooper, now they are also made by Messrs. Latimer Clark, Muirhead & Co. In the commutator instruments the commutators multiply or divide the readings by ten, thus increasing the range; but they are apt to get out of order.

Deprez's voltmeter or ammeter is much the same as Ayrton and Perry's in principle, though different in form. It has the advantage of a larger reading, as the deflecting coil is set at an angle, so as to give a large reading on one side and a small one on the other. Deprez's voltmeters and ammeters are made by Carpentier, and are used widely in France, though not well known in this country.

Messrs. Paterson & Cooper make a portable permanent magnet voltmeter. This is very convenient, as it is small enough to be easily carried in the waistcoat pocket.

Messrs. Siemens make a permanent magnet instrument, in which the needle is itself the standard magnet. The needle is of the form constantly used by Messrs. Siemens and Halske.

It is a sort of long steel thimble, slit nearly its whole length, magnetised as a horse-shoe magnet. The object of this form of needle was originally to make a reflecting galvanometer dead-beat; but in this case it is difficult to see why that form is used, especially as a metallic vane is attached to damp the vibrations, instead of the usual copper damper. The needle is deflected by a pair of coils, and is brought back to zero by the torsion of a spring, much as in the well-known torsion dynamometers. This instrument has the disadvantage that it is not direct reading, and, therefore, that it takes longer to read it. It is, also, more a laboratory than a workshop instrument. It contains both a permanent magnet and a spring; but it must be remembered, that if both weaken with age, the error due to one tends to counteract that due to the other. An error may also arise from the coils affecting the magnetisation of the needle.

Instruments with Electro-Magnetic Controlling Fields.

To avoid the error due to the use of permanent magnets, Messrs. Crompton and Kapp have introduced instruments in which the permanent magnet is replaced by an electro-magnet, the magnetising current being itself the current, or part of the current, which is to be measured. The electro-magnet is subject to so strong a magnetising force that it is practically saturated at the lowest reading required. As the current is increased the controlling field is not increased much, but the field due to the deflecting coil or strip increases in proportion to the current. In order to avoid the error due to persistent magnetism, the iron core is made very thin, and is, in fact, a few wires of soft annealed iron. In the Crompton-Kapp instrument at present in the market, the voltmeter and ammeter do not take the same form. The voltmeter has a pair of astatic needles mounted on a vertical arbor, with pivots and jewels. A controlling field is produced by two vertical electro-magnets fixed with their axes parallel to the arbor, and the deflecting coils are two similar coils without iron cores. The controlling and deflecting coils thus act on both needles. A fault in this form is that as the cores must be very strongly magnetised, a considerable magnetising force is needed, and the instrument, therefore, takes so much power to make it work accurately, that it gets hot. Instead of winding the active coils with German silver, the makers use copper, and put a resistance of German silver or platinoid in series with them. The question of winding with different wires to avoid heating will be discussed separately. The disposition of the deflecting coils is bad, as they take a great deal of power, and are so placed as to have comparatively little influence on the needle. The ammeter consists of two horse-shoe controlling magnets, arranged like two letters C, with their like poles put together. The needle is mounted with a cap, as in a mariner's compass, or, as the makers call it, "suspended." The deflecting field is produced by the current, or part of it. This instrument has the drawback of being affected by a dynamo, even at a distance, as the field due to the coils is weak. Care must also be taken in leading a large current to and from it. To avoid any errors due to the field produced by the connecting wires, the makers send out a long piece of flexible twin cable with clips. Placing the instrument so that the needle, when at zero, is in the meridian, or parallel to the external field due to a neighbouring dynamo, does not eliminate the external field error, as the needle is influenced as soon as it moves from zero. Mounting the instrument on a turn-table is, of course, inconvenient.

Mr. Crompton has lately made considerable improvements in these measuring instruments, his object being to use less power, and to get a stronger field, so as to avoid errors from external fields. His latest form, fig. 15, resembles the ammeter just described, but it has only one electro-magnet, as this takes less power to give even a greater controlling field. The chief improvement is, however, in obtaining a very much more open scale, and in adapting the ammeters to read very large currents directly. The current is led in and out at the side of the instrument farthest from the needle, so that any error due to the leads is practically eliminated. The index, instead of reading over the scale in the usual way, passes under it and turns over on the other side; but this is not shewn in the engraving. The scale itself is engraved on an annular flat strip, which is raised about an eighth of an inch from the dial to allow the index to pass under. The point of the index is thus directed towards the centre. This is of very doubtful advantage.

These instruments, though they are modestly called "current and potential indicators," are calibrated throughout their scales, and the dials are specially engraved. Though in the Crompton-Kapp instruments the errors due to persistent magnetism are reduced as much as possible, such errors must always exist to some extent, as the rising and falling curves of iron do not coincide even at the greatest magnetisation.

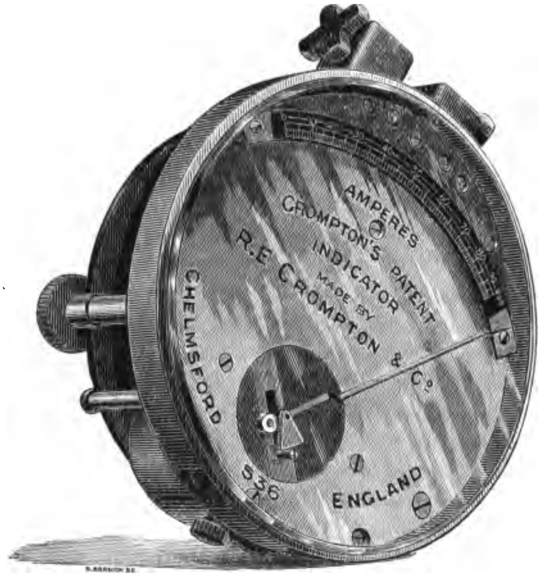


FIG. 15.

Messrs. Paterson & Cooper and the Thomson-Houston Company in America have also brought out instruments on the same principle. In both these instruments the iron core is much too large and the resulting error from persistent magnetism is considerable.

Mr. H. Davies has brought out an ingenious instrument. The current to be measured passes round the coils of a horseshoe electro-magnet, between whose poles there is a double needle system. This consists of a thin soft iron needle and a thick but shorter needle fixed at right angles to it. The two needles are mounted on an arbor so as to turn freely. When the current round the electro-magnet is small, the long thin needle determines the position of the system, but, as the current increases, the long thin needle becomes saturated, and the short thick needle, becoming more strongly magnetised, overcomes it, and tends to set itself in line of the field. This instrument, having a very strong field of its own, can be used near a dynamo, but of course its persistent magnetism error is large. It is calibrated throughout its scale, and is made by Messrs. Woodhouse & Rawson.

Before using an instrument of any sort which depends in any way on soft iron it should be tested for difference in readings with a rising and falling current. The current may rise gradually or not, but the falling current must fall very gradually, otherwise the error may not show. The best way is to vary the current by means of a water resistance. Voltmeters made with soft iron should always have keys, which should be pressed at the moment when a reading is to be taken. An instrument which gives very different readings with gradually rising and falling currents will often read quite accurately with a key. The key has another advantage, it prevents the heating of the coils. In most cases it is not necessary to leave the voltmeter on continuously, and so the temperature error due to the heating of the coils by the current itself is generally of little importance. Messrs. Crompton & Co. provide their voltmeters with commutators. Most voltmeters should have commutators, because they not only serve the purpose of keys, but they also allow any error due to the external fields to be seen at once and eliminated. Of course some instruments cannot have commutators, and in that case the whole instrument should be turned round to eliminate the external field error. Persistent magnetism errors are generally of far greater importance in ammeters, because from the difficulty of making the connections, especially when large currents are used, the instruments are left permanently connected up. Ammeters should always have a short circuiting switch. Even if the current is very large, so that it is difficult to short-circuit the ammeter completely on account of its low resistance, a switch that will reduce its current considerably below the normal will do. It may appear as if the writer overrated the importance of the magnetism error, but to show that

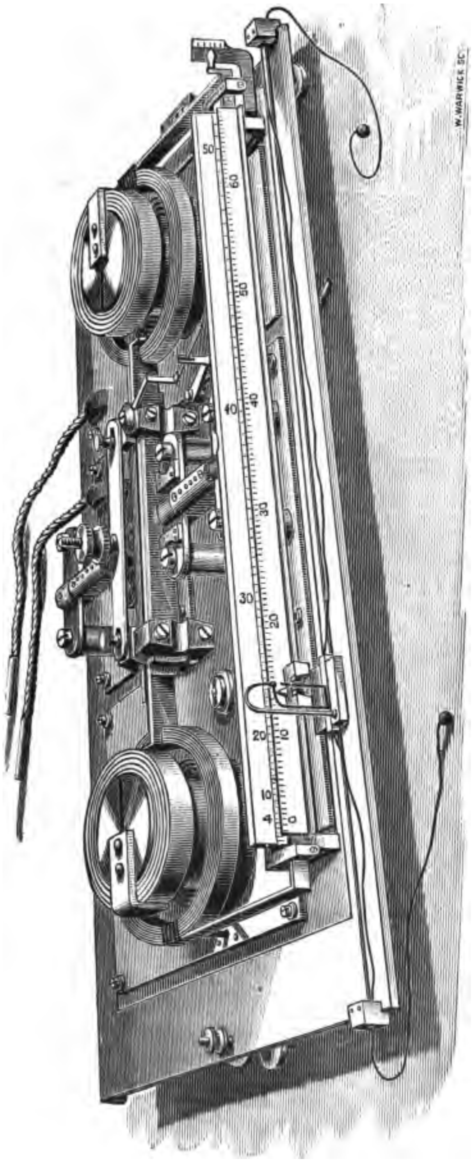


FIG. 16.

that is not the case, he may mention that being once asked to check the calibration of an instrument, containing soft iron, he found it on an average 30 per cent. wrong with a rising current, and the error went up to 70 per cent. with a current gradually falling.

Gravity Instruments.

The force of gravity is generally used in instruments for very exact work, as in the case of the various current weighing instruments, such as, for instance, that used by Lord Rayleigh, and in the various bifilar instruments. Sir W. Thomson has lately brought out a series, most of which consists of gravity instruments.

The gravity instruments are current weighing dynamometers, whose coils are balanced horizontally on a beam, and are attracted and repelled by fixed coils close to them. The instruments are not direct reading, but the force acting on the movable coils is balanced by weights. Fig. 16 is a view of a standard current balance. The chief novelty about these instruments is the method of bringing the current into the moving coils. The beam is not supported on knife edges as in a chemical balance, but is hung by means of a number of very fine wires, which are fixed side by side on the periphery of little trunnions. The trunnions are semi-circular in cross section. The ligaments, as Sir W. Thomson calls them, allow the beam to move with the most perfect freedom, and will carry such currents as 2,500 ampéres when required without heating. The wires are exceedingly fine, and the surface is very large. These are really very carefully designed, and accurately made standard instruments, which may be used by makers for calibrating commercial volt and ammeters. Of course, when once calibrated, they do not need to be re-calibrated, as there is nothing to alter in them. Sir. W. Thomson has also designed one as a direct reading voltmeter for commercial use. It reads over a short range so as to give large deflections through the range required in an installation. For instance, the inspectional voltmeter shewn in fig. 17 reads over a wide range between 90 and 110 volts.

Mr. Miller has brought out an instrument in which a small needle of soft iron is mounted on a horizontal arbor, and

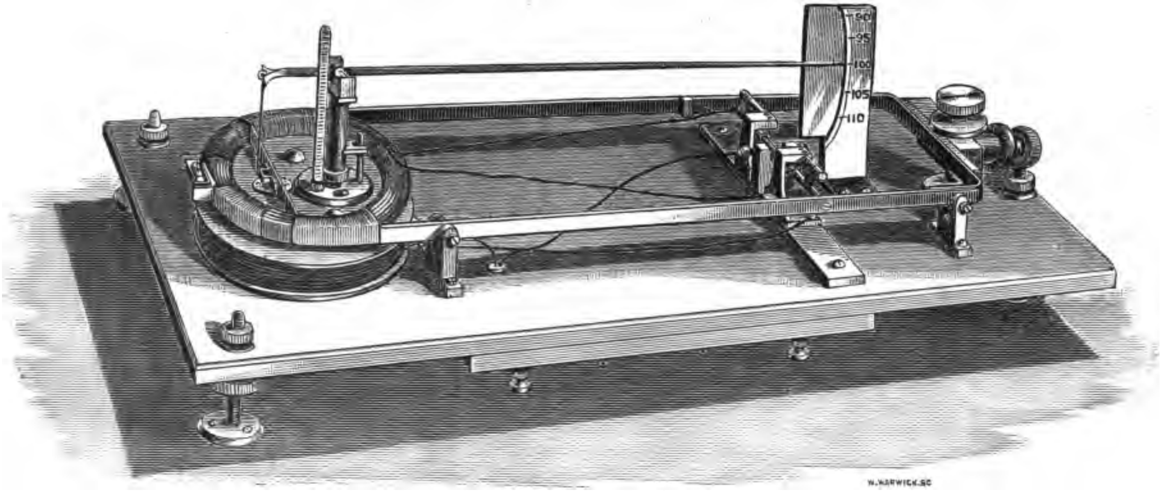


FIG. 17.

balanced so as to tend to hang in one position. The coil of wire is arranged so that when there is a current the needle is magnetised and tends to set itself according to the field. These Voltmeters and ammeters are made by Messrs. Sharp and Kent. The Miller Voltmeter seems to have been the forerunner of a large number of gravity instruments with soft iron cores.

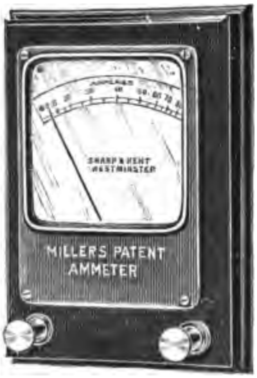


Fig. 18.

Messrs. J. G. Statter & Co. make an instrument on the same principle. In theirs the needle is not fixed centrally, but is on a little arm, so that its movement is not one of pure rotation, but partly of translation, as the needle is drawn up into the coil.

In such instruments the error due to persistent magnetism is very troublesome, and it is best to use a key or short circuiting switch. The error can be reduced by making the needles very light; but when they are so made the friction of the pivots becomes relatively important. Persistent magnetism in this case shows itself in two ways, one of which is probably independent of the degree of saturation of the iron, and depends on the direction of magnetisation. When the current is increased the iron not only becomes more strongly magnetised, but the direction of its magnetisation is altered, and as the iron is already magnetised at a slightly different angle, there is a tendency opposing its being as strongly magnetised in the new direction as it would have been if it had been held in that position before the current was started. This persistence of direction of magnetisation may be easily tested. If, without altering the current, the index be moved some little distance, first, say to the right, and allowed to come back very gradually, it will come to one reading; if it be now moved to the left, and allowed to return in the same way, it will come to a different reading. This error may not always be corrected, even by the use of a key, as when the circuit is made the needle vibrates before settling down to its final reading. The vibration is not so free as when the index is moved by hand with no current in the coils; this is no doubt due to the damping effect of the angular persistent magnetism. Messrs. Statter avoid the error, as far as possible, by making the needle almost in the form of a circular disc, and depending on the movement of translation rather than of the needle setting itself lengthways in the field. By using a small disc the moment due to the persistent magnetism is very small.

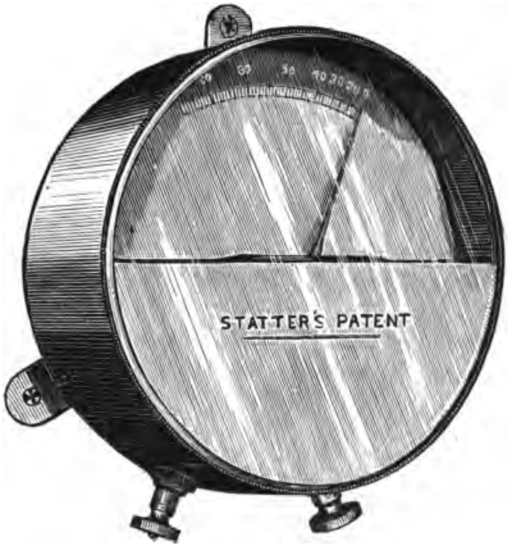


FIG. 19.

Messrs. Statter & Co. make their instruments to stand on a table, or to be carried in a wooden case. The latter is a very portable arrangement, as the instruments are small and light. They are then hung on gimbals inside the case, so as always to hang vertically. They also make them in another form (fig. 19) to be fixed against the wall of an engine room. One form is specially made to read over a large part of the scale with a small increase of electromotive force—this is very desirable for installation work.

Mr. A. Wright has made an ammeter in which the repulsion of two iron cores, surrounded by one coil, is balanced by the action of gravity. He did not put it into the market because it did not read the same with a rising or falling current. This is to be regretted, as the fault is common to all instruments in which iron is used, the error being only a matter of degree depending on the magnetisation of the iron.

Messrs. Siemens have made instruments on the same principle, but the best known in this country is Schuckert's, or Humnel's, shewn in fig. 20. The moving needle is a very light strip of soft iron; this is made in a curved form, so that when the index is at the end of the scale the needle is against the inside of the coil. The whole instrument is well designed and carefully worked out, the design being especially suited for manufacture on a large scale. The voltmeters seem to be wound with copper, which is a decided objection, but

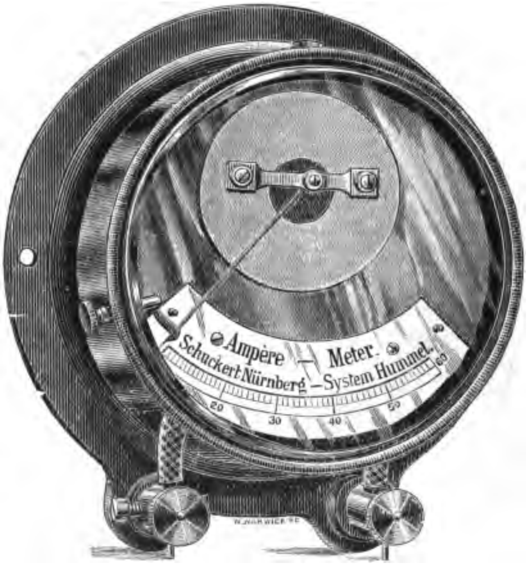


Fig. 20.

if temperature corrections are made the readings are accurate. The General Electric Apparatus Company are agents for these instruments in this country. Their appearance appeals to the engineer more than to the optician, and this is in their favour.

The writer, in conjunction with Mr. Evershed, made a gravity dynamometer, which did not depend upon a bifilar suspension. A coil is mounted on an arbor, which is made of German silver tube, with steel pivots let into the ends. This is mounted obliquely, and the centre of gravity is not in the axis of the arbor, so that the coil tends to set itself in one position. The moving coil is inside a pair of fixed coils. The coils are arranged to give a large deflection, the scale being spread out in the centre. Connection is made with the moving coil by means

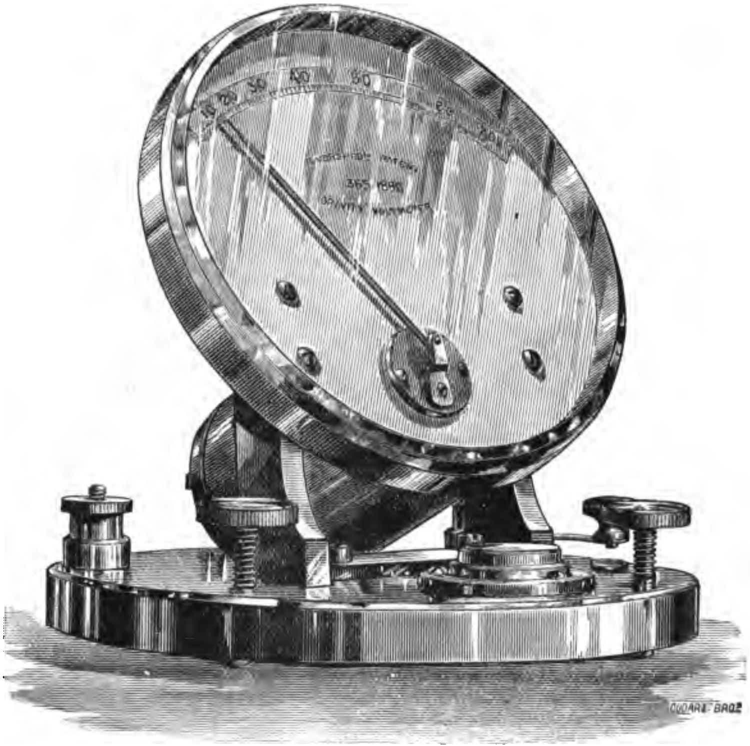


FIG. 22.

of mercury cups. This instrument reads over its scale with 13 watts. It is made as a wattmeter, the moving coil having the current. In the case of a voltmeter, the connections may be made by Helmholtz's arrangement; that is, by thin flexible pieces of copper foil or tinsel.

The Electrical Power Storage Company make instruments in which the reading is taken by noting the weight needed to pull an armature off the core of an electro magnet. A graduated lever has a rider which is pushed along till it pulls off the armature. This arrangement seems clumsy, and the persistent magnetism error must be very great if not carefully avoided, by pulling the armature off and replacing it just before reading. There seems to be no reason why such instruments should not be very accurate. Of course reading them is troublesome; but they are essentially workshop instruments, as the forces dealt with are large, and there is nothing delicate to get out of order.

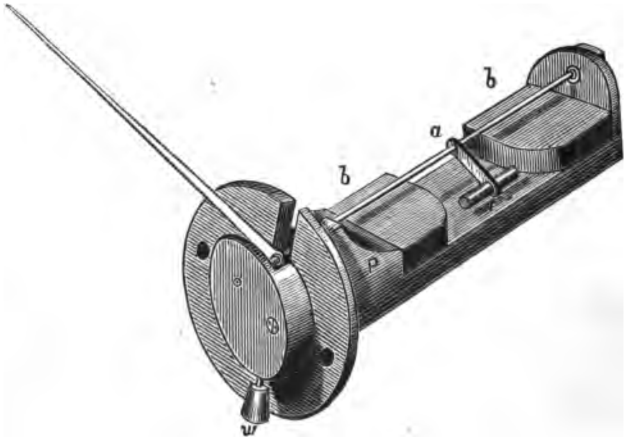


FIG. 23.

Messrs. Goolden & Trotter have lately brought out Mr. Evershed's gravity instruments (fig. 22). In these there is a coil, in the centre of which there is a sort of discontinuous core, consisting of two stationary pieces of soft iron, and one moving piece between them; these are mounted on a sort of plug which goes inside the coil, and is shown separately (in fig. 23); *r* is the moving piece and *b* and *b'* the fixed pieces. *w* is a counterbalance weight tending to bring *r* into the position shown. When the iron is magnetised, *r* is moved laterally, so as to get into the stronger field, as *b* and *b'* are filed into curves, so that the field is stronger on one side. The plug and coil are mounted sloping, so as to make the instrument easy to read. It is very carefully calibrated throughout its scale. The Voltmeter has a key. In the ammeters the lowest reading is about a quarter of the highest, and the error is very small with a falling current. Mr. Evershed anneals the iron very carefully, and removes the magnetic oxide by dissolving it, as he finds filing hardens the iron. The scale can be spread out where desired by altering the shape of the curves of *b*, *b'*. The instrument reads freely, as the pivots are jewelled, and the forces are great and the inertia and weight of the moving parts small.

It will be seen that in this instrument the scale can be made almost as desired by filing the fixed iron pieces to the right curves. Thus a voltmeter may be made to read over a large portion of its scale between, say, 45 and 55 volts while an ammeter can be made to read through a long range and give readable deflections throughout.

In the ammeters, from 200 ampère turns at the lowest reading to 700 at the highest are found to give very small differences in rising and falling over the whole scale. In the voltmeters, only 100 to 300 ampère turns are used so as to get high resistance. Thus a voltmeter for 100 volts measures at least 1,000 ohms. A key is used to avoid persistent magnetism errors.

Messrs. Paterson & Cooper make a gravity ammeter which consists of a single bar of copper passing behind a permanently magnetised needle whose deflection is resisted by the force of gravity.

Spring Instruments.

The Siemens dynamometer is too well known to need any lengthy description. In it there are two coils, one fixed and the other movable, and suspended vertically. In its normal position this is at right angles to the fixed coils, and when there is a current in both coils they tend to set themselves in the same plane. This tendency is resisted by a spiral spring which is tightened by turning a milled head until the movable coil is in its normal position, the force due to the current being exactly balanced by that of the spring. The angle the top of the spring has been turned through can be read off, as there is a pointer attached to the milled head to which the top of the spring is fixed. The force tending to turn the suspended coil varies as the square of the current, and the force of the spring varies directly as the angle it is turned through; the current is therefore proportional to the square root of the angle the milled head is turned through. Electrical connection with the coil is made by means of mercury cups. If the instrument is a voltmeter both coils are made of fine wire; if an ammeter thicker wire is used. The ammeters have generally two fixed coils made with different numbers of turns, so that a larger range is obtained. These instruments are graduated in degrees, and a table of reference is given. This is a bad arrangement. It would be much better to mark the instruments in volts or ampères directly. At present working with them is very tedious. It takes some time to adjust the spring so as to bring the coil back exactly to zero, especially as the instruments are anything but dead beat, and if one has then to refer to the table to find out what the reading means, the waste of time becomes serious. A great deal has been said against the permanence of springs. The prejudice seems to be really undeserved. A bad spring does grow weaker in time, but if a good one is used to start with it is practically permanent. Kohlrausch has recently made some exhaustive experiments on this subject, and has found that good springs may be implicitly relied on for all ordinary purposes. Moreover, watchsprings work with a regularity which is beyond the accuracy of any commercial voltmeter or ammeter. An error of 1 per cent. would amount to a quarter of an hour a day in a clock, so that springs which work within a few seconds in a day can cause no perceptible error in a measuring instrument. The Siemens dynamometer has the advantage that it follows a simple law with accuracy, so that it is easy to check the instrument, as it need be calibrated at only one part of its scale, the rest of the readings being calculated. The spring can therefore be easily tested now and again. The writer found one Siemens dynamometer, which was carefully recalibrated, alter about 1 per cent. per month. This was not a new instrument; moreover, makers are more careful now than they were in those days. In addition, either the original calibration was wrong or the spring had weakened considerably since the instrument was sent out. A Siemens dynamometer is easy to make, but great care should be taken to select springs that can be relied on. These instruments should also be provided with commutators, if they are required for use near dynamo machines. As the reading is the same whichever way the current goes, all that is wanted is to commute the current and take a second reading. A Siemens dynamometer is thus free from many of the common errors. If a spring is good it is practically free from change due to age; by means of a commutator it can be freed from error due to external fields; it reads the same with a rising as with a falling current; the coils are well ventilated, and the instrument does not necessarily need much power to work it, so that the coils need not get hot, and, finally, if wrong, it can be calibrated again.

Dr. Fleming and Mr. Gimingham have designed a dynamometer for use as a voltmeter or watt-meter (fig. 24). It consists of two fixed deflectors, AA′, BB′, each of which is made of a pair of solenoids with their ends arranged so as to make one solenoid with a consequent pole in the middle. Two moving coils, C, C′, are supported so as to encircle the consequent poles of the solenoids, the coils being of larger diameter so as to be over the consequent poles. These coils are mounted on an arm, which is supported on a metal point, and fitting into a metal cap. The force acting

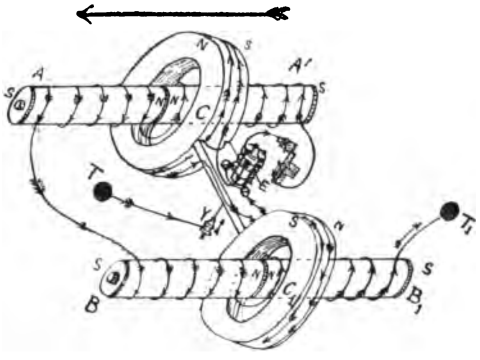


FIG. 24.

on the movable coil is balanced by turning a milled head, as in the Siemens dynamometer. The current enters by the spring E, and goes out by the metal cap. This latter does not seem a good arrangement. The instrument is portable, and should be constant, but it is not direct reading, which is a drawback. The coils are arranged so that it can be used close to a dynamo without being affected.

Professors Ayrton and Perry's long range spring instrument is most ingenious. It consists of a coil of wire, in the centre of which is a small tubular core of soft iron, in such a position that it is attracted into the solenoid when there is a current. This motion is resisted by a spring of a peculiar form. It is made of a long narrow strip of hard phosphor bronze rolled round a small mandrel so as to make a spring a few inches in length. The bottom of the spring is fixed to the low end of the tube inside it, while the top is fixed to a nut attached to the glass over the dial. The tube reaches a little above the dial, and the index is fastened to the top of it. When the core is attracted down into the solenoid the spring uncoils, thus turning the tube, and with it the index. The spring is so made that a very small movement of the tube produces a deflection of some 200 degrees. By this exceedingly pretty device a very simple long range instrument is obtained. The dial is horizontal, and has a mirror to avoid errors in reading which might otherwise occur, as the index is necessarily some little distance from the scale. The soft iron tube is made as thin as possible so that it may be saturated easily. This is important, as the more the iron is saturated the less is the persistent magnetism error. The writer is told that the error due to persistent magnetism is too small to matter throughout most of the scale, though it is 1 per cent. or so at the beginning. This instrument is free from many errors. It is very portable, and it does not need recalibration if good springs are used. Professor Ayrton has carefully checked an instrument from time to time during the last two years, and finds that if there is any weakening of the spring, it is so slight as to be imperceptible, being so small that it is insignificant in comparison even with the small errors that are unavoidable in calibration. The earlier voltmeters were shielded, that is to say, the solenoids themselves were placed inside a tube of soft iron. This arrangement is now abandoned. The iron is itself magnetised by the solenoid, and as it is only slightly magnetised, it causes no persistent magnetism error. It is unnecessary to shade it, as the instrument is not perceptibly influenced by external fields, as the core moves bodily, while an external field merely tends to turn the core round like a compass needle. These instruments may therefore be used quite close to a dynamo if desired.

The scales are printed, and the instruments are made to fit the scales by adjusting a subsidiary movable coil till they read correctly. The scale is divided up into equal divisions. In discussing the Ayrton and Perry ohmmeter, it was pointed out that it is generally impossible to make an instrument follow the proportional law accurately; and it is a pity that these instruments are not calibrated carefully throughout the scale. In practice the adjustable coil is moved till the readings are right at two points about quarter and three-quarters of the full reading, so that the average error is small. The writer has the scale of an Ayrton and Perry instrument before him, which has been carefully calibrated throughout. It is right at each end of the scale, but wrong in the middle. The curve of the attraction of a core into a solenoid can never become a straight line, but this can be to a certain extent corrected by putting the core in such a position that when it is drawn into the solenoid it moves into a position where the force is lessened. The more recent instruments are much better. The inventors have had an exceedingly complimentary letter from no less an authority than Professor Weber, confirming their accuracy.

Professors Ayrton and Perry's scales are here criticised somewhat exactingly, because the instruments are so good otherwise, and so very largely used, that such a fault is a matter of considerable importance. Probably others of the instruments already described are very much more incorrect than that whose scale has just been mentioned, as some makers do not seem to take the least trouble to calibrate correctly, but the writer could not order a collection of the latest instruments by different makers to test their calibration; moreover, he has not at present the means of checking them.

Sir W. Thomson has brought out a voltmeter (fig. 25) in which a small spheroid of very soft iron is deflected by a coil. The spheroid is supported by two stretched platinoid wires, so that when it tends to set itself in the field due to the coil, the tendency is opposed by the fine stretched wire.

One would expect that this instrument would be affected by angular persistent magnetism, as the spheroidal form, though it lessens the lagging of the total magnetisation, which is generally known as hysteresis, or persistent magnetism, does not tend to reduce the angular persistent magnetism. Sir W. Thomson has, however, carefully investigated this point, and finds there is no error from persistent magnetism of either form.

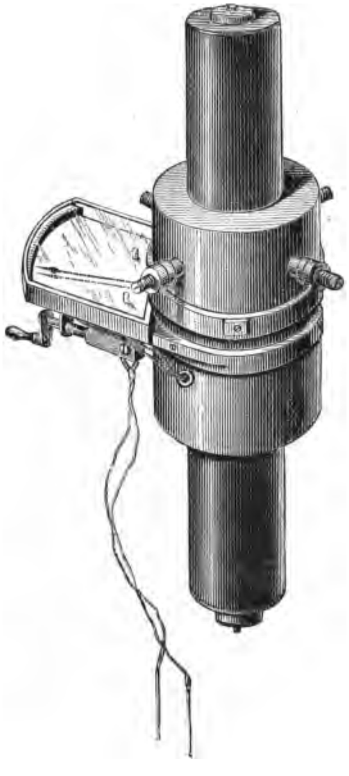


FIG 25.

In Cunynghame's volt and ammeters an electro-magnet acts on a soft iron core so as to turn it. The core is mounted on a vertical arbor, to which a pointer is attached. The turning force due to the electro-magnet is opposed by a spring, which is turned till the pointer on the arbor comes to zero. This spring is operated by a milled head with an index, as in the Siemens dynamometer, but the scale is graduated directly in volts or ampères, as the case may be. The force measured is great, so that any error due to friction is small, and the field due to the electro-magnet is strong, so that external fields produce no perceptible errors. The persistent magnetism error must be great, as the cores of the magnet are large ; so that care should be taken not to read with a gradually falling current. The error due to angular persistent magnetism is probably small, as the core cannot turn much, being held by stops. Messrs. Woodhouse and Rawson manufacture these instruments.

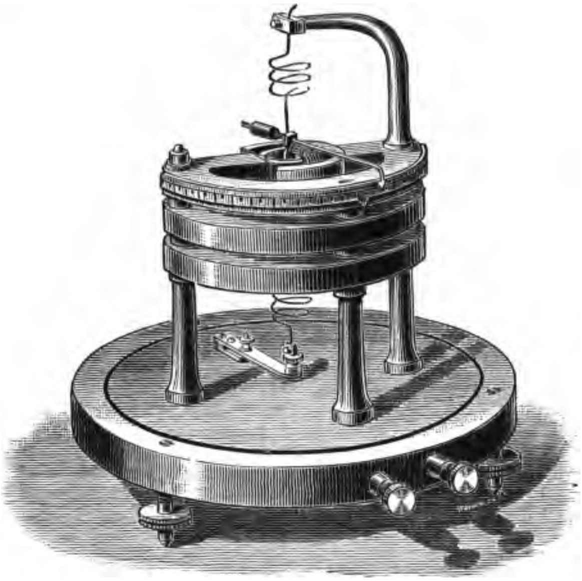


FIG. 26.

The d'Arsonval industrial instrument is shewn in fig. 26. The cut explains itself. These instruments need very little power to work them, and should be much better known in this country. Like the galvanometer, they can be made perfectly dead beat. The proportional scale should not be depended upon, and the instrument should be calibrated throughout the range. It is impossible to get the field uniform enough for the proportional law to hold.

There are several instruments which do not belong to any of the classes discussed above. Of these Captain Cardew's voltmeter is the most important. In this a fine wire is heated by the current and its expansion is measured. The Cardew voltmeter has undergone many improvements since it was first brought out. What is called the "Admiralty" pattern will be described first. This is shewn in fig. 27. This is a general diagram, and is not absolutely correct in every detail. What is known as the "Admiralty" type is generally vertical, but in the figure the instrument is shewn horizontal, thus embodying the latest improvements. Fig. 28 is another view.

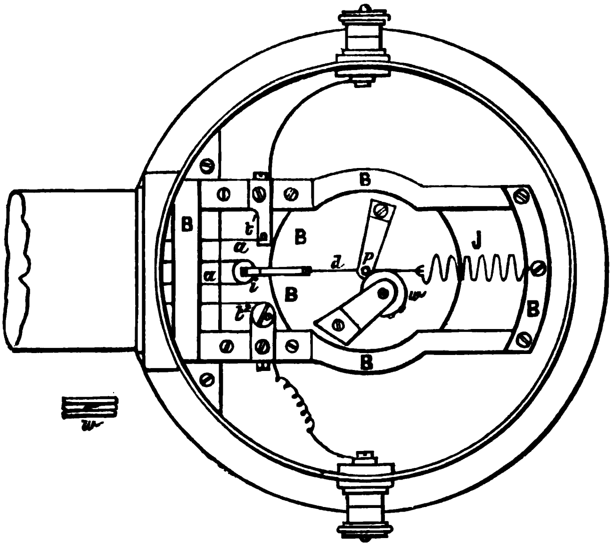


Fig. 27.

The wire, *a*, *a*, is stretched inside a long tube. It starts from t^1, which is connected with one terminal, and is stretched along the inside of the tube, and passes over a small ivory pulley and returns to *i*, which is connected with the spring, J. After passing over the ivory pulley, *i*, it is led to the other end of the tube again, over another pulley, and back to t^2. There are thus four wires passing through the tube. The ivory pulleys at the end of the tube are attached to a casting which is fixed on the ends of two rods. This arrangement is to enable the wire to be threaded easily, as the tube or outer case can be removed without interfering with the adjustment of the wire. The wire is

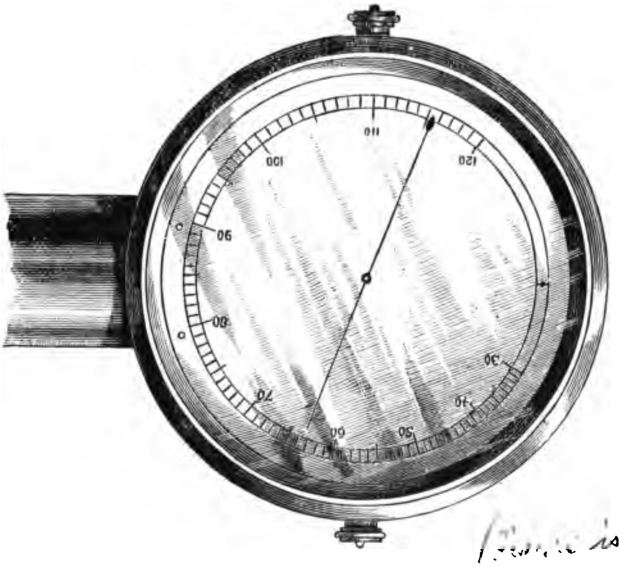


FIG. 28.

(There is a wide division.)

doubled backwards and forwards to get a greater length, and thus a higher resistance. As far as the expansion is concerned, it is that of two lengths of wire, and the pull of the spring, J, is against two thicknesses of wire. The pulleys at the end of the tube are made to run with very little friction, and are carefully pivotted in jewel holes. The friction of the pulley, *i*, is not so important, as that the expansion of the two loops of wire should be the same. *i* is attached to the wire *d*, which is wound round a pulley, *w*, which is turned with two grooves. The wire passes from one groove into the other between two screws as shewn in the side view of the pulley. This prevents the wire slipping relatively to *w*. It passes on to the spring, J. The spring, J, is simply to keep the wire, *a*, *a*, taut. The readings do not at all depend on the strength of the spring, as it is too weak to be able to stretch the wire in the least. A little toothed wheel is attached to the pulley, *w*, and gears into the pinion, *p*, to which the index is attached. In the earlier forms of instrument the spring was attached to a pulley of diameter different from that to which *d* was fixed; the result was that there was a strain on the arbor of *w*, which caused friction at the pivots. The wire for this type for 120 volts is ·0025 in. in diameter, and is of platinum silver; the resistance is about 30 ohms per foot. This instrument takes 40 watts at 120 volts. Though this is high, it must be remembered that this voltmeter has no temperature errors like those of electro-magnetic instruments. The temperature of the wire is in practice about 200° C. at the higher readings. The reading evidently does not depend on the absolute expansion of the wire, but on the relative expansion of the wire and bars. The bars are therefore made of steel for part of their length and brass the rest, so that they have the same coefficient of expansion as the wire. If it were not for this, the instrument if set to zero at one temperature would not come to zero at another. The rod arrangement has a slight error, because, as the rods do not entirely envelop the wire, the wire coils cool more quickly than the rod, so that if the instrument after reading 120 volts or so, is used to read 20 or 30 volts, the wire is colder than it ought to be relatively to the rods, so that the instrument reads too low.

Though the instrument is compensated for temperature as regards the lengths of the rods and wire, there is another source of small errors; and that is the rise of resistance of the wire when the voltmeter is used in a very hot room, or its fall if the room is cold. This error amounts to about 1·6 per cent. between 0° and 50° C. The makers propose to add a little rheostat and a thermometer, so that this error can always be corrected. If it is known before hand that the instrument is going to be used, for instance, in an engine room at, say 80°, it can be calibrated for use at that temperature. As the zero is apt to be altered by rough usage or shaking, the end of the wire, t^2, is attached to an adjusting screw, so that a little wire can be taken in or let out without interfering with the rest of the instrument. The 60-volt type is much the same as the 120-volt, except that the wire is shorter and thicker. The power emitted by a given surface is obviously less with a thick wire than with a thin, because the heat is carried away largely by convection and conduction. The surface of the wire and the power spent are the same as in the 120-volt instrument, but the wire is shorter, being 8 feet instead of 12; the wire, therefore, reaches a higher temperature, and the expansion is the same as in the long wire voltmeter. The object of using the rods to support the wire is to overcome the difficulties of stringing the wires, and of taking the voltmeter to pieces to examine or repair it without necessitating recalibration; but, as explained, they cause a small error. This difficulty has been surmounted by the following ingenious device. A temporary rod is screwed in and the wire is strung and arranged. The little casting to which the ivory pulleys are attached is then screwed to the outer tube. The rod is then removed. The outer tube is made of iron and brass, so as to compensate for temperature. A short piece of very fine wire is put in circuit to act as a fusible cut-out, though a sudden rise of temperature will often fuse both wires. The whole mechanism is fixed to a brass framework, B, B, as the old wooden cases were found to warp and alter.

The Cardew voltmeter has always been used vertically till lately, and the little convection currents inside the tube cause the index to keep moving so that a reading cannot well be taken within 1½ per cent. This difficulty is quite got over by placing the instrument horizontally. This simple, but valuable modification, is due to Mr. Ram. Prof. Ayrton had also found out the same thing. Of course the instrument must be calibrated in the horizontal position; those who possess vertical voltmeters must not turn them on their sides and expect them to be accurate. A horizontal voltmeter can be read within ¼ per cent. through its ordinary range. These voltmeters are very carefully calibrated, and a curve of each is taken, and the readings are transferred to a dial by a special apparatus, and engraved. The expansion of the wire practically follows a simple law, but each instrument is calibrated throughout its scale. The Cardew voltmeters above described are made by Messrs. Goolden and Trotter. Messrs. Paterson and Cooper also make Cardew voltmeters, but they differ considerably in details of construction.

Captain Cardew has devised a standard instrument which has no friction and an optical arrangement for reading; but, as it is more a laboratory than a workshop instrument, it need not be described here.

The Cardew voltmeter is free from most of the usual errors. The chances of error can only lie in the wire itself, which may gradually alter in resistance. It does not seem to do this, however, measurements taken after a year's constant use showing no change. The voltmeters are overrun before calibration as a precaution.

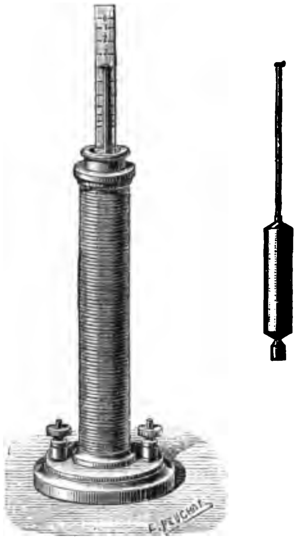


FIG. 29.

M. Lalande has lately brought out an instrument which is a sort of electro-magnetic hydrometer. It consists of a coil or solenoid with a glass tube in the centre: this contains water or some other liquid, in which floats a small hydrometer with a soft iron rod enclosed it in. This idea is really very old, as Iremonger brought a hydrometer ammeter before the Electrical Society somewhere about 40 years ago. The difficulty with such an instrument is in getting a long range, though no doubt it may be, and probably is, done by properly shaping the solenoid and core. It may be easier to make such an instrument sensitive through a small range, which is what is wanted for installation work. Messrs. Sharp and Kent make the "Lalande" ammeters and voltmeters, and Mr. J. A. Berly also supplies them.

For very high electromotive force it is generally best to use an electrometer, as it takes no current to work it. Of course, a high-resistance voltmeter may be used, but it is impossible to make a coil for commercial use whose insulation will stand, for instance, 2,500 volts. If a voltmeter had a certain number of ampère turns at, say 100 volts, and the wire was, say 10 mils., the diameter for 2,500 volts would be 2 mils., and the coil would get hot, because so much space would be taken up by the insulation. External resistance can be added in series instead of being wound on the coil, and this is, perhaps, the best way of working in many cases. The drawbacks are, that the voltmeter and its resistance will absorb a great deal of power, and that it is dangerous to work with such high electromotive forces, as it would be easy to get a fatal shock by disconnecting the wires from the voltmeter and retaining the ends in the hand. For this reason, it is better to use an electrometer, though most electrometers are anything but workshop instruments. An electrometer should be connected with a dynamo or leads by circuits which contain some damp string or a carbon megohm, or some other very high resistance, so that if anyone does accidentally touch the terminals, the current through will be too small to do any harm.

Sir William Thomson has lately brought out a gravity electrometer. This is suitable for direct current work, but as most high electromotive forces which need to be measured are met with in alternating current work, it will be described later.

The ordinary torsion electrometer is sometimes used for measuring high potentials in practical work. The needle and one pair of quadrants are connected to one terminal, and the other quadrant is connected to the other terminal. The force then acting on the needle is as the square of the difference of potential. However, the only use for electrometers in direct-current work is in arc light installations, and an electrometer is not the sort of thing an electrician in charge of an installation would take to as a rule, as he would much prefer to work with ammeter only, and let the electromotive force take care of itself.

Mr. Arthur Wright has made and used for some time an ingenious electrometer. It consists of a fixed and a movable plate. The latter is supported on an arbor which turns very freely and is not quite vertical, so that the plate tends to move into one position. The planes of the plates are not quite parallel, so that the attraction turns the movable plate so as to bring it nearer the other. This instrument is chiefly used for localising leaks. By measuring the difference of potential between the terminals of the machine, and between each terminal and the earth, the position of a fault can be localised with considerable accuracy. The weak point of this is, that its accuracy is interfered with by a very slight alteration in levelling.

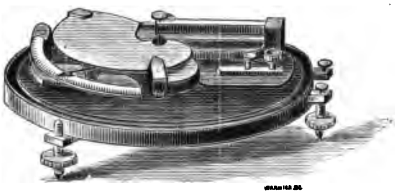


FIG. 29A.

There are many instruments, such as Weston's, Lippmann's, &c., which have not been described. They have been omitted because they are not well known, or in general use in this country. There are also many which are still in the experimental stage or are laboratory instruments only.

CHAPTER III.

WATTMETERS.

Nearly all wattmeters, or instruments for measuring electrical power, are modifications of Weber's dynamometer, in which a fixed coil produces a field and tends to turn a movable coil. Electrometers are occasionally used, especially in alternating current work. The best known wattmeter is Siemens' dynamometer wound specially with one fine wire coil, which is put in shunt to the part of the circuit in which the power is to be measured, and a thick wire coil which is put in series. The force is then proportional to the product of the currents in the two coils, that is, to the product of the electromotive force and current, or to the power. This instrument has the same advantages and faults as the Siemens dynamometer voltmeters already described.

In addition to these they have an error which exists in all wattmeters on the Weber dynamometer principle. Suppose the power spent in a lamp is to be measured. If the fine wire or pressure coil is put in shunt both to the lamp and current coil, the current through it is proportional to the fall of potential in the lamp and current coil; and if the pressure coil is in shunt to the lamp alone, it must be in series with the current coil, and the current in the current coil is not the same as that in the lamp, but is the sum of the currents in the lamp and pressure coil. As the pressure coil generally takes more power than the current coil, it is best to put it in shunt to the lamp and current coil. This error may be very considerable. Suppose, for instance, that the fine wire is in shunt to the lamp only, and that its resistance is 500 ohms. Suppose two lamps are to be measured which require 50 watts each, taking 100 volts and ·5 ampères, and 50 volts and 1 ampère. With the 100 volt lamp the pressure coil will have ·2 ampère, and the current coil ·7, the product representing the force will be ·14. If the 50 volt lamp is measured the pressure coil will have ·1 ampère and the current coil 1·1, and the product will be ·11. Thus if the wattmeter is right with the 50 volt lamp, it will be no less than 27 per cent. wrong with the 100 volt lamp. With smaller lamps the error will be still greater. When the power to be measured is very large in proportion to the power absorbed by the instrument itself, the error is negligible, but wattmeters are mainly used for incandescent lamp work, for which they are generally unfit.

The writer has introduced a method of winding, which eliminates this error. If the fixed coil is the pressure coil it is arranged in shunt to the lamp and current coil. A few turns of wire are fixed in shunt to the current coil so as to subtract from the pressure field an amount equal to that due to the resistance of the series coil. The field due to this compound pressure coil is then proportional to the difference of potential of the lamp terminals, though there may be an additional fall in the thick coil itself. It is best to have the current coil fixed, however, for several reasons. It is easier to make connection with a coil carrying a small current; and it is difficult to make a shunt to a low resistance coil with mercury cups or other connections which will always preserve the same relative resistance. If the current coil is fixed, the pressure coil is arranged in shunt to the lamp only, so that the current coil carries the pressure coil's current in addition to its own. As many turns as there are in the current coil are then wound backwards round it and put in series with the pressure coil, so that when the lamp is removed so as to give a difference of potential without current through the lamp, the index is not moved.

A properly compensated wattmeter should give no deflection when there is a large current and no electromotive force, that is when the instrument is set to measure the power in a short circuit, so that the pressure coil only has a current if it is in shunt to the current coil; and it should give no deflection when there is electromotive force and no current, that is to say, when it is set to measure the power in an open circuit, so that there is no current in the current coil unless it is in series with the pressure coil.

Profs. Ayrton and Perry have brought out a wattmeter. It is a dynamometer, but has the advantage of being direct reading. It is made by Messrs. Paterson & Cooper.

Messrs. Fleming & Gimingham's instrument may be wound as a wattmeter. They correct the error by a double reading method.

CHAPTER IV.

METERS.

These may be divided into energy and quantity meters. In an incandescent lamp installation, for instance, the electromotive force is, or ought to be, kept constant, so that a meter which measures the total quantity of electricity in meg-coulombs will serve the purpose just as well as one that gives the energy used or work done in meg-joules or horse-power hours. On the other hand, if the consumer is running motors with varying loads, and the electromotive force in the mains is not kept constant, an energy meter is required.

The most obvious way of measuring the quantity of electricity is by means of voltameters. If the average current is large a voltameter cannot be put in the main circuit, as it would waste too much power and would be too bulky. Mr. Edison places little voltameters in shunt to small resistances in the main circuits. The plates are zinc in a neutral solution of zinc sulphate. A resistance of German silver is inserted in the main circuit, and the voltameter is put in shunt to it. A resistance is in series with the voltameter.

These meters have been in extensive use in the States for some time, but they are little known in this country. One would expect some difficulty in making them accurate. If the meter and its circuit is put in shunt to a high resistance, so that there are two or three volts on the voltameter circuit when the house is using say, 50 lights, there will be an excessive loss of power in the meter resistance amounting to 2 or 3 per cent. of the whole power used. The loss of power is not the worst, the loss of electromotive force due to the resistance makes the lamps burn dull and the light, which is what the consumer pays for, is diminished seriously, so that the meter may itself be the cause not only of what amounts to an error of 10 per cent., but also of a dead loss of 10 per cent. of the light. The insertion of resistance in the main house-circuit is therefore to be carefully avoided, as it reduces the available electromotive force just at the time when it is likely to be low owing to the resistance of the street mains. If, on the other hand, the voltameter is put in shunt to a very low resistance, which is the usual practice, the electromotive force on the voltameter circuit is too low when only a few lamps are on, and the least back electromotive force set up in the voltameter cell will cause large errors. The voltameter cell has a resistance in its own circuit, so that any electromotive force in the cell itself causes as small an error as possible. Voltameters are said to give inaccurate results because of slight differences of density in the solution or of materials in the plates, which give rise to local currents when there are no lights on, and the cells are practically short circuited through low resistances. This is probably the case, more especially with copper voltameters, and Mr. Edison has given up the use of copper, perhaps for that reason. Mr. Wright uses small copper voltameters in the Brighton installations. The lamps are arranged in groups of eight or three, and each group has a cut-out wound with high resistance wire to put in a new lamp if one of the group is broken. A little copper voltameter is put in series with the high resistance coil, and the time the consumer has used each group of lamps is thus known. The consumer, of course, short circuits a group out when he does not want it.

M. Faure has devised a meter in which a wire carrying the current is made to rotate round a pole of an electro-magnet. The torque was supposed to vary as the square of the current, and the speed of revolution was supposed to vary as the square root of the torque, so that the speed was as the current. The number of revolutions was counted, so that the meter read in coulombs or ampère hours. The rotating wire made a contact every revolution, putting an electro-magnet into circuit. This electromagnet worked a ratchet wheel, which worked the index mechanism.

Mr. Ferranti's meter is on the same principle as M. Faure's. It has a short vertical electro-magnet, with a space filled with mercury at its upper pole. The electricity flows round the magnet core, and is then led into the iron. It flows from the iron into the mercury, and flows through the mercury radially to the other terminal. As the mercury has a radial current, which is crossed by the lines of induction from the magnet, it rotates. A small vane is immersed in the mercury, and rotates with it. This vane works the counting mechanism, which is a very beautifully made meter train, about the size of a watch, the various pivots being made to work as smoothly as possible in carefully jewelled holes.

In such an instrument the torque is not proportional to the square of the current, unless the iron is so slightly magnetised that the induction in it varies as the magnetising force. Mr. Ferranti has, therefore, made the iron in the form of a short cylinder, and it is very slightly magnetised. This introduces another trouble, as the persistent magnetism error comes in. The friction of the mercury and counting mechanism also does not follow any simple law, so that a meter made to read correctly at one current does not read correctly at another. Most people would have given up the design on meeting such difficulties as these; but Mr. Ferranti made an exhaustive series of experiments, making meters with every conceivable form of magnet, vane, and mercury vessel, with the end in view of making a meter in which the various errors would neutralise one another. After some years of work the meter has been made into a commercial instrument, and is now in the market. Mr. Ferranti is now working out a meter for alternating currents. This is a modification of that just described, with the electro-magnet laminated and compound wound.

Profs. Ayrton and Perry's meter consists of a clock, with a coil attached to its pendulum or balance, and another fixed in such a way that it assists or acts against the force of gravity, so that the clock is accelerated or retarded. One coil is of high resistance, and is in shunt to the house circuit, so that its current is proportional to the electromotive force, and the other carries the main current, or part of it. The retarding effect is thus proportional to the product or to the power used. The amount the clock loses or gains in any period is thus proportional to the energy used during that period. The inventors have gone into the matter thoroughly, and find that small accelerations or retardations are exactly proportional to the force. As a clock is a very accurate instrument, an increase or decrease of vibration frequency may be small, and may still be large in comparison with any variation due to bad regulation of the clock. As this meter measures energy, it may be used to measure the quantity in an ordinary parallel installation; but it will also do for work where both the electromotive force and current vary from time to time. It is simple to make, as all that is necessary is to add the coils to an ordinary clock, and to regulate it again.

It may be necessary to set such a meter carefully, so that the earth's field does not affect it. The high resistance coil must be on the balance, as it would be difficult to lead a large current to a moving coil. Profs. Ayrton and Perry's meter is made by Messrs. Latimer, Clark, Muirhead & Co. It is called an "ergmeter." Why not "joulemeter" to match "voltmeter," "ammeter," &c.? Following the same nomenclature, such an instrument as Mr. Ferranti's ought to be called a "coulommeter," or "coulombmeter." Coulommeters are generally graduated in ampère-hours. This is objectionable, as "ampère-hour" is a barbarous perversion of terms, and there is no advantage in such a practice, as consumers are charged either by the 1,000 watt-hour—another horrible unit—or by the lamp-hour—generally by the lamp-hour. If the meter is to be used without a coefficient, it should be graduated in lamp hours, the lamps used being known to the maker of the meter before it is marked, otherwise the meter should be graduated in coulombs.

The Aron meter is a modification of Aryton and Perry's. In it there are two clocks. The pendulum bob of one is a permanent magnet, and a coil with the main current is placed below so that it increases or lessens the downward force so that the clock goes fast, or slow. The consumption is then proportional. One form is shewn in fig. 31. A new modification has lately come out, in which the clocks are coupled with differential gear, to work the index. This arrangement is very much simpler.

The Cauderay meter, which was described some years ago in the Review, consists of a small cylinder with pins on it, like a musical-box barrel. This is driven at constant speed. An ammeter is placed so that the end of its index moves along the barrel from end to end as the current increases from 0 to its full value. There is a little wedge-shaped piece on the end of the index, and when a pin passes, it presses the index away from the barrel in a direction at right angles to the direction of movement of the index due to the ammeter. The index is thus quite free except when the pin is gearing and pushing it back. The barrel has more pins at one end than at the other, so that when the current is large the index is pushed back more frequently. A bar is arranged behind the index, so that whenever the index is pushed back the bar is moved too. This bar works the counting mechanism by means of a ratchet arrangement. As the barrel goes at a constant speed, and the pins are arranged

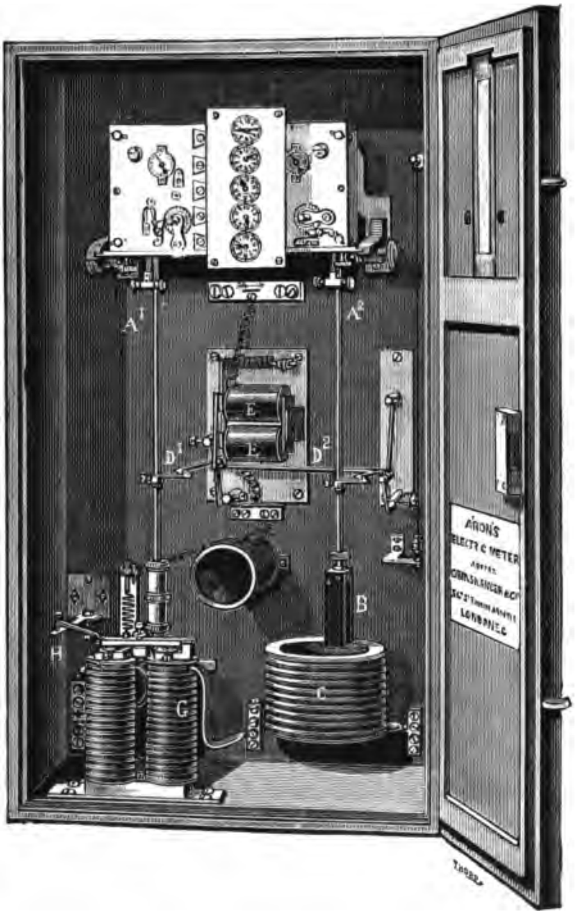


Fig. 31.

on the barrel so that the frequency of the pushes given to the index and bar vary as the current, the counting mechanism records the quantity of electricity passed. The barrel is driven by a heavy balance with a driving escapement. The balance is connected with two soft iron armatures, which receive an impulse once in six vibrations or so. This balance is so arranged that it gets an impulse at starting, so that the meter always starts. The driving mechanism is connected in shunt to the house, so that it starts as soon as the main switch is turned on.

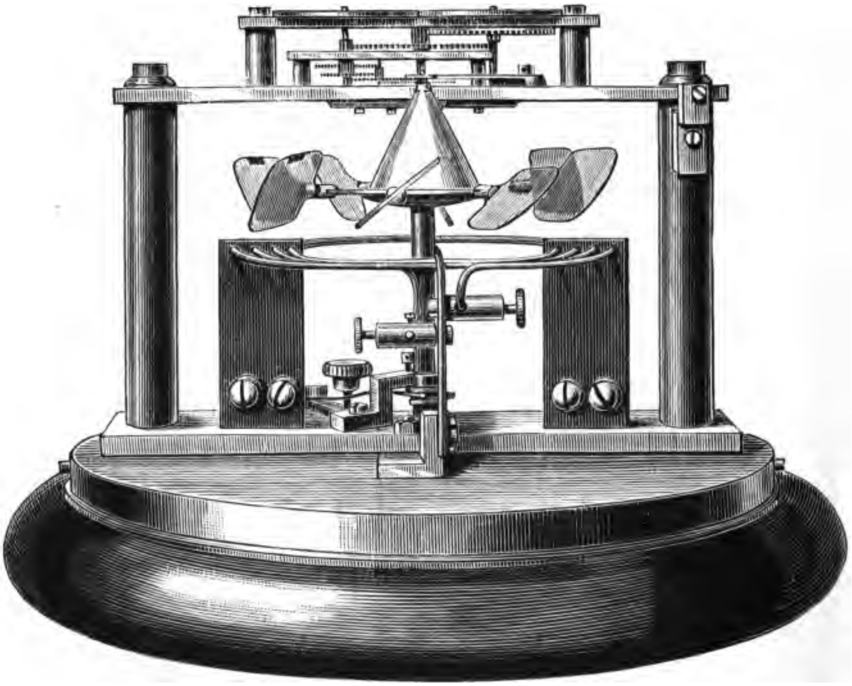


FIG. 32.

The ammeter is rather rough, but it is being replaced by a dynamometer-ammeter. This will admit of the instrument being wound as a coulommeter or joulemeter; and it will do for alternating currents approximately when used on the lamp circuit.

Professor Forbes' meter is shown in fig. 32. The main current is led through a coil of wire so as to heat it. This heats the surrounding air which rises and actuates a fan with oblique blades. The rotation of this fan works the index mechanism. This is certainly a beautifully simple instrument. It is difficult to believe that it is capable of very great accuracy, as it must be troublesome to arrange the coil of wire and the fan so that the speed of rotation is proportional to the current. Prof. Forbes seems to have succeeded in doing this. The friction of the point and cap on which the moving parts rest, and the friction of the index train, must also give trouble. Mr. Ferranti had enormous difficulty in getting index trains that would do for his meter. The friction of the point and cap will also increase with use. In a tangent galvanometer the point soon becomes round. Prof. Forbes' fan is exceedingly light, so as to lessen this as much as possible.

Mr. Edison, Dr. Hopkinson, Profs. Ayrton and Perry, and many others, have designed meters containing motors driving various kinds of brakes. Various more or less complicated meters, containing clocks, have also been designed by Mr. Swan and others. Mr. Boys has taken out several patents for electric meters and integrating apparatus; but as these have not come into the market yet, it is not necessary to describe them.

Dr. Siemens's meter, fig. 33, may be taken as an example of the motor meters. It consists of a motor with a permanent magnet. The armature of the motor is in shunt to a resistance in the main circuit, so that the torque varies as the current. The motion is resisted by a cylinder of copper, which is arranged between the outside of the field magnet and an extra soft iron stationary armature. The revolutions are counted by an ordinary meter train. This meter was invented by Professors Ayrton and Perry, and is included in their patent of 1882.

This meter has many sources of error. The resistance in the main circuit is very objectionable, as already explained, in connection with Mr. Edison's meter. Any back electromotive force in the armature prevents the torque being strictly proportional to the current in the main circuit. The resistance of the brush contacts may vary considerably, and will probably increase very much in proportion to the whole meter circuit, when the meter has been running for some months in a place of the sort usually allotted to gas meters. The torque needed to turn the copper cylinder between the magnet and armature varies as the speed, and the meter would no doubt register fairly accurately if there were no friction; but the friction is always a large part of the whole load. The result is that the meter does not begin to register till the current has reached a certain value. Dr. Siemens proposes to get over this by using two meters, one being calibrated for small currents, and the other for large, one or the other being put into circuit by an electromagnet; but this arrangement would also be inaccurate. In Mr. Ferranti's meter, which is really a form of motor meter, there are no brush contacts, and the resistance is inappreciable.

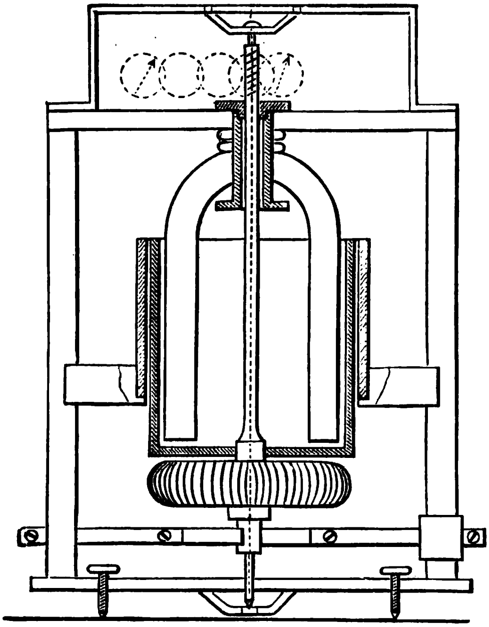


FIG. 33.

CHAPTER V.

WINDING OF VOLTMETERS.

Though the subject of these papers is not the manufacture of instruments, there are some questions regarding winding which must be discussed.

Some years ago it was generally supposed that voltmeters should be wound with German silver, because its temperature coefficient is small. Lately, however, the practice has been altered, and it is generally, but erroneously, considered best to wind with copper, because, though its temperature coefficient is greater, the power absorbed by a given volume at a given current density is less.

The error due to differences of temperature must be due to differences of temperature of the room, or to rise of temperature due to the current in the coils. If a voltmeter wound with copper wire and calibrated at 50°C. were used in the engine-room of a steamer, it would read about 5 per cent. too low; whereas, by the use of German silver, with its ingredients in proper proportion, the error would be comparatively small. German silver is very much better than copper, as far as alterations of external temperature are concerned. Platinum silver and gold silver alloys need not be discussed, as they are too expensive for ordinary use in voltmeters.

The rise of temperature due to the current depends chiefly on whether the voltmeter is used continuously or not. It has already been pointed out that most voltmeters have persistent magnetism errors, and should therefore be provided with keys, so that the error does not come in. The instruments which have persistent magnetism errors are just those that take a great deal of power to work them, and are therefore apt to get hot if left on. The error from rise of temperature due to the current or power error is therefore avoided by the key, which also avoids persistent magnetism errors. Such instruments as

Sir Wm. Thomson's "graded" galvanometer take so little power, even when wound with German silver, that the power error is less than the room error.

Profs. Ayrton and Perry read an elaborate paper before the Physical Society (June 13th, 1885), in which, starting with certain assumptions, they showed that to make the power error least voltmeters should be wound with copper. The writer dissents entirely from this view, as the assumptions are unwarrantable.

If two voltmeter coils of a certain volume were wound with copper wire and German silver wire respectively, and the wires were of the same size so that the number of turns were the same, the power spent in the German silver coil would be very much greater than that in the copper coil, if the current, and, therefore, the ampère turns, were the same in both. The specific heats taken by volume would not be widely different in the two cases, so that the German silver coil would rise to a higher temperature in a given short time than the copper; and though the variation in resistance per degree of rise of temperature for a copper coil is much greater than for a German silver one, the German silver coil would rise so much higher that its percentage alteration of resistance would actually be greater—that is, assuming the temperature coefficient generally given in books and tables. This would also be true when the ampère turns were the same in both cases, and the coils wound to work with the same electromotive force instead of the same current, if the insulation occupied no room.

In a fine wire galvanometer coil, the insulation, instead of being a mere thin skin outside the wire, occupies four or five times the space that the wire does. If a voltmeter wound with reasonably small wire, as for instance 100 or even 50 volts is made with copper wire, the insulation will cut down the volume of the copper so much that it would have been better to have used German silver with a coefficient of ·044 per cent. per degree C.

The question may be asked, What is German silver? Mr. George B. Prescott has lately been looking into the matter, and finds that writers always talk of German silver as if it were a definite alloy, and give its specific resistance and temperature coefficient, but never say what they mean by German silver.

Mr. Prescott finds that the specific resistance varies enormously according to the proportion of nickel, and that the temperature coefficient falls as the specific resistance is increased by adding nickel. Mr. Prescott has studied the question for Mr. Weston. The following table is quoted from his article. The specific resistance is given in weight in pounds of a wire a mile long and an ohm in resistance.

GERMAN SILVER ALLOYS.

EXPERIMENTS BY EDWARD WESTON.—TEMPERATURE ABOUT 75° F.

Alloy No.	Parts.			Weight per Mile-ohm. lbs.	Per centage of Nickel.	Remarks.
	Copper.	Nickel.	Zinc.			
64	100	20	50	11,572	12	
83	100	30	50	14,599	17	
55	100	33	50	15,325	18	Re-melted.
62	100	33	50	15,448	18	Re-melted.
60	100	33	50	15,626	18	Re-drawn.
63	100	30	30	15,599	19	
65	100	40	50	18,054	21	
101	100	50	50	18,172 (?)	25	New Lot Nickel.
79	100	50	50	19,009	25	
92	100	50	50	19,077	25	Lost Weight.
90	100	50	50	19,594	25	
91	100	50	50	19,670	25	
77	100	50	50	20.354	25	
78	100	50	50	21,402	25	
...	100	78·74	52·75	24,485	34	

Mr. Prescott gives no temperature coefficients, and this is much to be regretted, as that is the information of most consequence. For voltmeters an alloy is wanted with the lowest specific resistance and the lowest temperature coefficient; for resistance coils the temperature coefficient is the most important.

The alloy known as platinoid is, according to Mr. Weston, simply German silver, with a large proportion of nickel, the slight addition of tungsten having no effect. The writer has tested many samples of platinoid wire, and has not succeeded in finding any traces of tungsten. There seems to be great difficulty in getting the tungsten to alloy, and Mr. Weston's views appear to be correct.

In considering the various nickel alloys there is another point that must not be overlooked, and that is permanence. Before makers can safely use platinoid or German silver with much nickel, it must be shown that the resistance does not alter with time.

Some makers prefer to wind voltmeter coils with copper wire and put an external resistance of German silver wire in series, and where this can be done it is the best arrangement. The power absorbed in the whole instrument may then be less than would have been taken by the coil or coils wound with German silver, and give the same ampère turns. Messrs. Crompton & Co. wind the active coils with copper, and put a German silver resistance in series nine times the resistance of the coils. The temperature error due to the room is thus very small, and the instrument does not heat so quickly as it would if the active coils were wound with high resistance wire, as a lower current density can be used in the resistance, so that there is more metal for each joule to heat. If a voltmeter is to be left on continuously, so that the specific heat does not come in—that is to say, so that the coils rise to that temperature at which rate the heat is carried away by radiation and convection, is equivalent to the power spent, the external resistance arrangement is again superior, as it may be easily ventilated.

So far it has been assumed that what is wanted is a given number of ampère turns in a coil of given dimensions. As a matter of fact, however, in all voltmeters, except, perhaps, Crompton's or Cunynghame's, in which there is a practically closed magnetic circuit, the relative positions of the ampère turns is of paramount importance. Thus an Ayrton and Perry ammeter, wound with 100 turns of uniform wire, would give a smaller reading with a given current than it would with 50 turns of small wire wound inside and 50 of large outside, occupying the same total space. They therefore wind the wire in several layers of different sizes. The considerations as to the use of German silver or copper wire, apply just the same whether it is a question of total ampère turns or of their disposition, provided a coil is wound with the same size of wire throughout. It would be of little use discussing the question of the best winding when a voltmeter coil is wound with wires of different sizes, as makers do not generally care to go into such refinements. The action of the coils in most voltmeters is also incalculable. In such instruments as Schuckert's, Statter's, and Ayrton and Perry's, the best effect would be got by winding the inside layers of fine wire, especially the parts where an ampère turn has most action and a turn of wire is short. A voltmeter might generally be wound with two sizes of wire with advantage.

Lord Rayleigh has used the induction balance for testing coils for leaks between wire and wire. If the coil, with its ends uncoupled, affects the exploring coil, the insulation is bad.

* * *

CHAPTER VI.

CALIBRATION OF VOLTMETERS.

It is very strange that so many makers pay so little attention to the accurate calibration of their instruments. There are instruments in the market which are well designed and well made, but are useless, or worse than useless, because the calibration is bad and the graduation wrong. Perhaps the reason is that many makers are engineers rather than electricians, and look upon calibration as an intricate scientific operation which cannot be performed successfully without expensive apparatus and enormous trouble; or perhaps they think accuracy of calibration of little importance, as most engineers have no means of checking instruments. If a buyer complains that two voltmeters got from different makers do not agree, he is told by each that the other's voltmeter is incorrect.

Very great accuracy is not at all necessary for practical electric light work, but a voltmeter should certainly be correct within one-half per cent. throughout its scale. It is doubtful if there is at present one instrument in the market which is within this limit; though one or two makers are now awakening to the necessity of accurate calibration. Ammeters are not quite so important, but the cost of maintenance of installations is enormously increased by lamps being run too dull or too bright; and until engineers have voltmeters which are correct and electric governors to ensure the right electromotive force, incandescent lamp illumination will be seriously handicapped. The idea that any compound dynamo preserves sufficiently constant electromotive force for incandescent lamps is a mere delusion.

Voltmeters are best calibrated by means of a standard cell. Various standard cells have been proposed by different writers, but the Latimer Clark seems to be much the best, and, for the present, it will be assumed that one is used. In order that the Clark cell should give its standard electromotive force it is necessary that it should give no current, otherwise it suffers from polarisation; it is therefore balanced against the fall of potential over a resistance through which a current is flowing, the current being supplied by another source. This is known as the Poggendorff method.

The Poggendorff method was originally a disposition by which the electromotive force of one cell was balanced against that of another by means of resistance boxes or rheostats; one of the cells had, however, to supply the current. This arrangement was devised in 1841. About 20 years later Du Bois Reymond made a modification of the opposing principle, in which the rheostat was replaced by a stretched wire. Mr. Latimer Clark has also worked at the subject more recently; and the wire and slide arrangement for comparing the electromotive force of two cells without taking the current from either of them is known as Clark's potentiometer. The term potentiometer has lately come to denote merely the wire and slide arrangement of Kirchhoft's bridge.

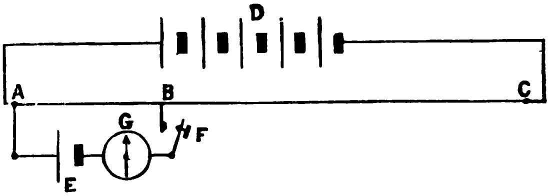


Fig. 34.

There are very many ways of arranging the standard cell and slide, one is shown diagrammatically in fig. 34. D is a battery which causes a current in the wire, A, B, C; there is, therefore, a gradual fall of potential between A and C. E is a standard cell, it is in series with a galvanometer G, and the key, F, which is connected with the sliding contact B. If B is slid along till there is no deflection of the galvanometer when the key is pressed, the fall of potential between A and B is equal to the electromotive force of the cell, and exactly balances it.

The electromotive force between A and B is thus measured against the electromotive force of the cell when the cell is not giving any current. If the electromotive force of the cell is known, and the resistance of A, B, is known, the current through A, B, can be got at once. If the resistance of A, C, is also known, the electromotive force between A, C, can be also calculated. It is not necessary to know the exact resistance of A, B, and A, C; all that is needed is the ratio of the resistances. If A, C, is a wire of uniform resistance, so that any inch of it has the same resistance as any other inch of it, it is only necessary to know the relative length of A, B, and A, C. A, C, is therefore generally a wire stretched over a scale.

Suppose the cell gives 1·438 volts and the resistance of A, B, is 10 ohms, or, say, its length 10 divisions, and of A, C, 700 ohms or divisions, there will be a difference of potential of 100·66 volts between A and C, and of 99·22 between B and C. If a voltmeter had been arranged in shunt to A C, B, having been moved to balance E while the voltmeter was in circuit, the electromotive force of the voltmeter would have been determined in comparison with the standard cell.

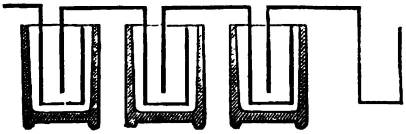


FIG. 35.

In practice, the battery, D, is made up of little secondary cells capable of giving the highest electromotive force ever wanted. Little Planté cells will do for this purpose, as only very small currents are necessary. To avoid the expense and trouble of connections to each cell, the lead may be bent as shown in fig. 35, so that the reduced plate of one cell serves as the peroxide plate of the next.

Messrs. Sowerby, of Gateshead, make little pressed glass cells which are admirably suited for this sort of work and are very inexpensive. The cells are made up in batteries of 10 or other convenient numbers. A little mineral oil is floated on the top of the dilute acid to avoid spray. This not only prevents the acid spray from corroding the connections and from attacking any metal work that may be near, but is also valuable as an insulator, as it tends to creep over the edges and down the sides of the cells.

The greatest care must be taken to insulate not only the cells but every separate piece of apparatus used in calibration work. Even those accustomed to laboratory work are apt to make serious errors by neglecting to insulate everything properly. Many of the troubles of leakage may be avoided by arranging the apparatus in such a way that small leaks do not matter; but it is generally safest to insulate everything as well as possible to begin with, so that it is not necessary to depend on ingenuity in subsequent disposition. If the charging dynamo gives lower electromotive force than is needed for calibrating, the cells are coupled in parallel for charging and in series for discharging. Fig. 36 to 38 represents a convenient arrangement for charging and discharging. Suppose the dynamo gives 60 volts, the circuit is led through a resistance to the mercury cups, *a* and *b*, which are holes in an ebonite slab filled with mercury. The cells in groups of 20 are connected with one set of terminals to the mercury cups, *c*, *d*, *e*, *f*, *g*, *h*, and the others to the cups *i*, *j*, *k*, *l*, *m*, *n*. The cups, *o*, *p*, are connected to the wires to the volt-

FIG. 36.

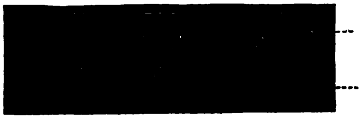


FIG. 37.

FIG. 38.

meters and rest of the apparatus. The slab has three lids which have wires passed through so that one makes the connections as shown in fig. 36 for charging, one disconnects the dynamo and puts the cells all in series for discharging giving 240 volts, fig. 37, while the third puts, say, three sets in series, and two sets in parallel, giving 120 volts and twice the current, fig. 38. It is advisable to disconnect the dynamo altogether when the cells are in use, as there are always ground leaks in the dynamo frame which might give trouble. The various wires and mercury cups should also be well insulated.

Cells with plates made of plain sheet lead take a little time to form well enough for constant use. A few holes punched in them, and filled with red lead, will give them enough storage capacity at once. This arrangement of the cells needs resistance to reduce the electromotive force, so that any desired electromotive force may be obtained on the voltmeter to be calibrated. The resistance may consist of 30 coils of wire in 10 lots of 1 ohm, 10 of 10, and 10 of 100 ohms. Each set is connected to a dial with a handle. The dial may have the 10 contacts arranged round the circumference with an arm and central contact. This form of switch is very liable to get out of order, as the central contact goes wrong unless very well made. The writer has devised a switch to overcome this difficulty. In this there is no central contact, as the circuit is right across the cross-bar, which makes contact on each end.

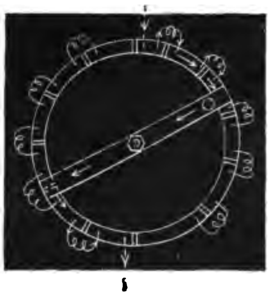


Fig. 39.

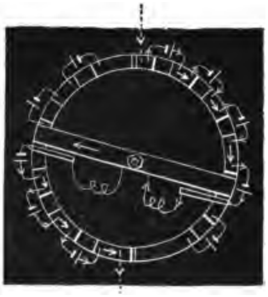


Fig. 40.

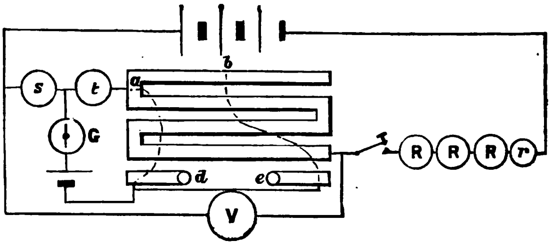
The segments are arranged so that the coils are short-circuited one after the other (fig. 39). Of course the cross-bar is turned through half the circle only to short-circuit out all the resistance. An ebonite handle is fixed to the cross-bar to insulate it from the hand. The electromotive force on the voltmeter may also be regulated by putting many or few of the cells in circuit. To do this, the slab and mercury cup arrangement is used for charging only, and for discharging the cells are coupled to two switches like those just described for the resistances. One switch puts the cells into or out of circuit one at a time, while the other does so 10 at a time. The switch must have a double contact and resistance arrangement, otherwise if the moving contact piece makes contact with one section before it leaves the other, the cell or the 10 cells between will be short circuited for a moment, or permanently if the switch is left in that position. If, on the other hand, the segments are so far apart that the contact piece leaves one before it touches the next the circuit will be broken for a moment and there will be sparking. The resistance contact arrangement was invented by Professors Ayrton and Perry. Fig. 40 is a diagram of a switch with 10 cells and resistance contacts. For sets of 1 cell the resistance should be about 8 ohms, for sets of 10 cells about 80 ohms.

The resistance method of adjusting will often be found most convenient, as the cell switches need 21 leads from the cells, which is troublesome if the cells are a little way off. A further adjustment is necessary if it is wanted to get electromotive forces of exact numbers of volts on the voltmeters; but this is not always required. A sliding contact arrangement, or some form of rheostat, will do.

The arrangement being complete for getting any electromotive force wanted by putting in more or fewer cells, or by putting resistance in circuit, the disposition of the standard cell may be considered. As most people have a Wheatstone bridge, a method will first be described in which a standard cell, a bridge, and a galvanometer are required. R, R, *r*, in fig. 41, are adjustable resistances and rheostat coupled up as shown. This resistance box is supposed to have coils for the thousands, so that when all the plugs are out 11,110 ohms are in circuit; *t* and *s* are two specially made-up resistances of 143·8 and 56·2 ohms respectively. The Clark standard cell is in series with a galvanometer, G. The standard cell circuit is from between *s* and *t* to the keys, so as to shunt the resistance of 143·8 ohms.

If the left-hand key is pressed it makes contact with the point *a;* but the right-hand key makes contact with *b*, so that if the plugs are drawn between *b* and *a*, there is a resistance of 1,110 ohms in the standard cell circuit. The object of the resistance *s* is to make up 200 ohms with *t*, so that the apparatus may be direct reading.

Fig. 41.



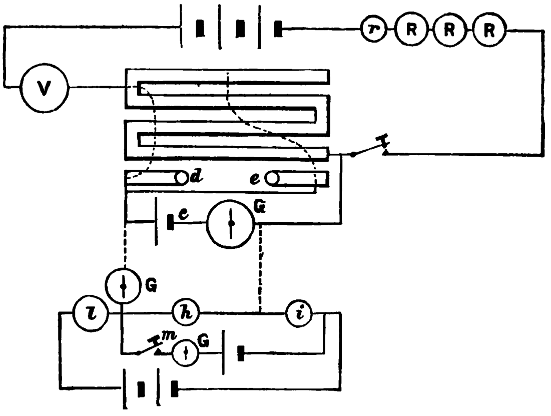


Fig. 42.

Suppose the voltmeter is to be calibrated up to 100 volts. To get 50 volts on it plugs are drawn in the resistance box to give 4,800 ohms, which, with *s* and *t*, make up 5,000 ohms. The resistances R R are then adjusted, till approximately 50 volts are on the voltmeter. The key *e* is then pressed for a moment. The galvanometer will be deflected, showing that there is too much or too little electromotive force. The switches, R, R, R, can regulate within 1 per cent., so that a pair of positions will be found one on each side of the desired resistance. The rheostat *r* is then adjusted till there is no deflection on pressing *e*. The key *d* is then pressed and a final adjustment made. The key *e*, and its resistances, are put to prevent a large current passing through the cell in either direction, and the key *d* must only be used for final adjustment. The 50 volt reading having been taken, 5,100 ohms are drawn, and the 51 volt reading is taken, and so on.

The sources of possible error are the heating of the bridge and voltmeter, inaccuracies of observation, and leaks. When the bridge has 100 volts on it, and 10,000 ohms drawn, it absorbs one watt, which is not likely to heat the coil enough to cause any serious error. Of this ·4 or ·5 is spent on the 4,000 or 5,000 ohms coil. The heating of the bridge would not cause any error if all the coils, including *t*, rose equally; but the error depends on the difference of rise of the resistance box coils and of the resistance *t*. There may be a small error due to the cell itself, being at the wrong temperature. The most serious temperature error will probably be in the voltmeter itself. If the voltmeter has a key, and is not meant to be kept on very long at a time, it must be allowed to cool after each reading; because, if it were calibrated right through at one operation, its resistance would rise, and the calibration would be wrong. During calibration the voltmeter key must be kept down, or a piece of metal may be put under it, and the circuit must be broken by the switch, as otherwise the whole electromotive force of the cells would come on the resistance box when the key was raised. If the voltmeter is meant for continuous use, and is not of high resistance, it should be left for some time with the electromotive force on it that it is intended to measure —as, for instance, the electromotive force in use at the installation to which it is going. The resistance box should, of course, be out of circuit in the meantime. If the voltmeter is of high resistance, so that it only uses one watt or so, it may be coupled up in series with the resistance box, as will presently be explained. The writer has not used a Wheatstone bridge in the manner described for any length of time; it must, therefore, be pointed out that there may be some danger in putting 100 volts on the coils, as they are wound double so as to have no self-induction, and in the 5,000 ohms coil there will be 50 volts between two wires, which are wound together. The coils on most bridges are very carefully insulated, being thoroughly well boiled in paraffin wax; but they are not intended for use with 50 volts on one coil.

If, instead of using an ordinary bridge, a special bridge is made, it can be made with twenty coils and two circular switches or contact dials, like those already described for regulating the electromotive force with ten coils of 100 ohms each, and ten or twelve of 1,000, will give readings up to 100 or 120 volts. The coils should be wound off the same wire throughout, so that they all heat equally with currents of short duration. If they are going to be used continuously, they should be made up of different numbers of similar bobbins, similarly wound. For all practical purposes it is enough to make all the 1,000-ohm coils alike.

It has been here assumed that the voltmeter is to be calibrated in legal volts. If what are known as B. A. volts are required, t must be 145·4 ohms, and s 54·6. The resistance may be measured in legal or B. A. ohms, as it is only a question of the ratio of the resistance of t to the whole resistance in shunt to the voltmeter.

If the voltmeter is not to be merely checked, but to be calibrated, the instrument's own scale is not used, but is replaced by a degree scale.

Messrs. Crompton & Co. do not engrave the scales directly on the dials, but on detachable segments. Each segment is fastened on by two screws, which are always the same distance apart, so that one segment engraved in degrees will fit any instrument. The readings are noted down and are plotted out on curve paper, with the volts and degrees as co-ordinates. The instrument is then graduated from the curve. The segment is screwed on a marking-off plate, which has a radial arm and a degree scale, and the segment is marked from the degree scale according to the curve. The curve method is necessary for two reasons. There are always small errors of observation due to the needles sticking slightly, or to inaccurate readings, and the curve eliminates these. Many arrangements for calibrating do not, like that just described, give the electromotive force varying volt by volt, but give the electromotive forces at random, and then measure them to some places of decimals. The curve then gives the position for each mark without calculation.

If the voltmeter is of such high resistance that its maximum current will not heat the bridge, it may be put in series. The arrangement is shown in fig. 42. The resistance of the voltmeter at the temperature at which it is wanted accurate is first measured. To know the electromotive force on it, it is then only necessary to know the current. The voltmeter is put in series with the adjustable resistance or battery switches and rheostat, R, R, *r*, and the bridge, as shown. The standard cell is in shunt to the whole bridge.

Readings are taken by drawing plugs and adjusting R and *r* till there is no deflection; thus, if with 288 ohms drawn there were no deflection, the current would be 1·438/288 = ·005 ampère, and this, multiplied by the resistance of the voltmeter at the temperature desired, gives the electromotive force which would give the same deflection at that temperature. The resistance of the voltmeter must be measured in the same ohms as those of the bridge. The electromotive force will of course be in legal volts if 1·438 is taken as the numerator. The drawback to this arrangement is that it is not direct reading. The simplest way of making the system direct reading is, perhaps, to shunt the voltmeter with a resistance, so that the resistance of the voltmeter and shunt is 688 ohms, or some simple multiple of it, ·688 being the reciprocal of 1·438. For every 100 ohms drawn in the bridge there will then be 1 volt, or a simple multiple of it, on the voltmeter.

The system can also be made direct reading by putting the standard cell on a local circuit. The standard cell *c* is then removed, and the leads are put, as shewn dotted, in shunt to the resistance *h*, which is on a local circuit, with its own cells and rheostat, *l*. The standard cell is in shunt to *h* and *i*, and *h* and *i* are so adjusted, that when there are 1·438 volts fall over them, the fall over *h* gives direct readings with the particular voltmeter being calibrated. The key *m* is used to adjust the rheostat *l*, and the keys *d* and *e* to adjust R, R, and *r*. Only one galvanometer is really needed, but two are shewn to make the diagram clearer.

Instead of putting the standard cell in shunt to a known and carefully measured resistance, the resistance slide or potentiometer may be used. This consists of a wire of platinum silver, or German silver, or platinoid stretched over a scale of convenient length. Professor Fleming, who is the great apostle of the potentiometer, prefers a wire having a resistance of about 1 ohm per foot. He also makes the potentiometer double, so that for an 8-feet wire the instrument is a little more than 4 feet long. Platinum silver is here mentioned because there may be some little difficulty in getting either German silver or platinoid wire sufficiently uniform for the purpose. The difficulty of getting wire which is perfectly uniform is one of the chief objections to the use of the potentiometer. Of course the wire may be calibrated, and in any case it must be checked before use ; but it would be too tedious to make a scale specially to fit an uneven wire ; and it is not likely that any wire will be perfectly even in resistance along its length. Even if it were perfectly even at first, it is apt to be stretched in use, and it may get bent or scraped. The instrument is also cumbersome and inconvenient, as well as inaccurate, and in spite of its being advocated by Prof. Fleming the writer thinks its use should be avoided, the more accurate methods with measured resistances being preferable. For work where great accuracy is not necessary, as in calibrating instruments for commercial use, which need not be within less than, say, ¼ per cent., a potentiometer may be used.

Fig. 43 shows an arrangement in which the potentiometer is in series with a set of resistances. D is a set of secondary cells, with switches, M, N, for putting any number in series, L is a set of carefully-measured resistance coils. If the voltmeters to be calibrated run up to 120 volts or so, the resistances, L, should be so high and so well ventilated that they do not get perceptibly hot with 120 volts left on for some time ; E is the standard cell, and G the Thomson or d'Arsonval galvanometer as before. There is a resistance, H, in series with the galvanometer and standard cell. This is short circuited out by closing the switch, F. When the right position for the sliding contact, B, has been found approximately, the switch, F, is closed to make the final adjustment. The resistance of the potentiometer wire, A, K, is first measured. The resistance coils, L, should be made of the same metal or alloy, so as to have the same temperature coefficient; so that there are no errors from differences in the temperature of the room. Before beginning to calibrate an instrument the battery, D, should be tested for leaks to earth. It is certain to have some leak, and one end may be more or less earthed. The pole which has the ground contact must be connected to A, so that the potentiometer may be at the same potential as the earth. The reason for this arrangement is that the potentiometer is apt to leak, as it is difficult to make such an instrument with perfect insulation. Besides the body is at the same potential as the earth, and the various keys and contacts in connection with the potentiometer may be imperfectly insulated from the observer when in use.

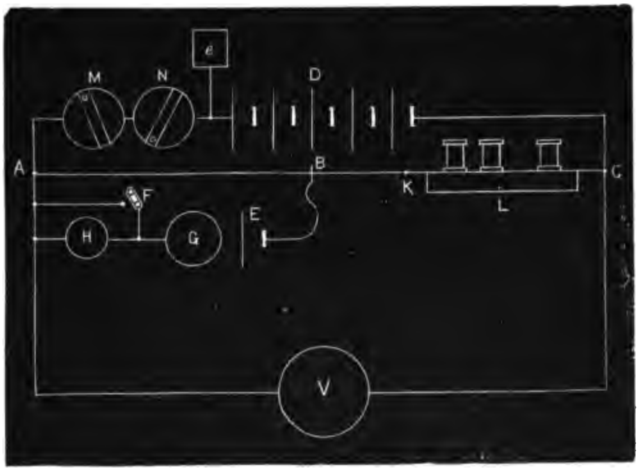


FIG. 43.

If instead of switching the cells in and out, so as to get the desired electromotive force, resistance switches are used, they must not be put between D and A, as when low electromotive forces are required the potential of the potentiometer would differ from that of the earth by that lost in the resistance. The resistances should, therefore, be between D and C. The resistances themselves may be badly insulated from the earth, and in that case it is best to make a good contact between the earth and the end of the potentiometer which is connected to A. Any small leak in the resistance coils then causes local earth currents only, and does not cause any difference of potential between the potentiometer and the earth or body. The earth plate *e* is shewn on the wrong side of M and N in figs. 43 & 44. The question of leaks has been discussed at some length, because it is only by very careful attention to details, apparently so small, that accurate work can be done. Slight leaks are a great source of inaccuracy in calibration. Small errors are sometimes ascribed to thermo-electromotive force due to the contacts of the potentiometer, but these errors are no doubt due to leaks, to changes of specific resistance by heating, or to cells running down, as the contact forces are far too small to produce such effects.

To calibrate a voltmeter it is put in shunt to the resistances, K, and to the potentiometer, as shown. Any electromotive force near the lowest reading required is then put on, and the sliding contact, B, is moved till there is no deflection when it is touched down. More accurate adjustment is then made with the switch F closed. If B does not come in a convenient part of the scale of the potentiometer, the resistance, L, is altered and a new adjustment is made. The distance from A to B is then read off on the scale, and as the resistance of the wire, A K, is known, the resistance of A B is known. It is then compared with the resistance between A and C, and the electromotive force on V is thus obtained; as the resistance A B : A C : : 1·438 : electromotive force on V. Another cell is then put in circuit and the process repeated. The resistances, L, should be adjusted so that the contact, B, is not moved very much; if the resistances, L, were arranged so that with 10 volts B came close to K and were left so till there were 100 volts on V, B would be moved $\frac{9}{10}$ths of the way to A, and any unevenness in the wire would cause errors to creep in. This arrangement is not direct reading, so that there is waste of time in using it.

The potentiometer may be arranged as a local circuit with its current supplied by a local cell or battery. Fig. 44 shows an arrangement with a local potentiometer circuit. The cells, D, may be insulated with great care, but it is probably best to consider a leak inevitable, and to earth the point A, or one end of the battery as shown. V is the voltmeter which is being calibrated. *t* and L are high resistances capable of taking the highest electromotive forces required. *t* is much less than L, so that there is a fall of one or two volts only over it. *a*, *d*, is the potentiometer wire, and H is a secondary cell supplying it. *l* is a rheostat or adjustable resistance. This is for adjusting the current in the wire and keeping it constant. Keeping the current constant by adjustment saves calculation, but it is not necessary. Besides, a large cell does not run down appreciably.

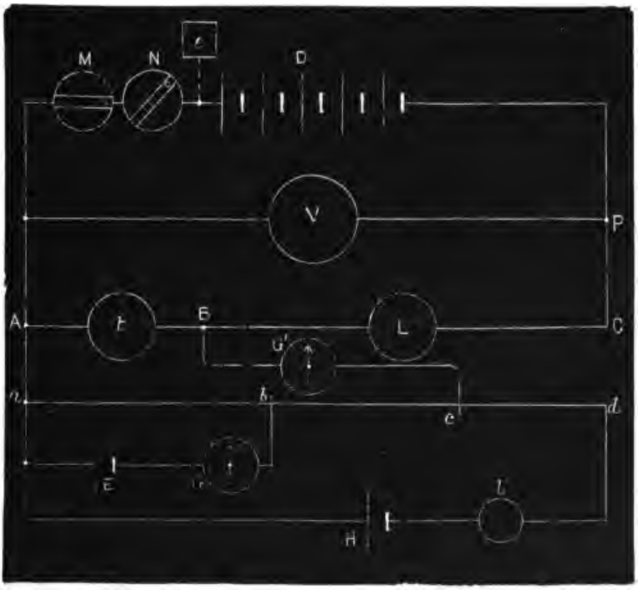


FIG. 44.

E is the standard cell, and G a galvanometer in series with it. Another lead is taken from B, through the galvanometer G′ to *c*. The potentiometer then compares the fall of potential over *a*, *b*, with that over *a*, *c*. The electromotive force on the voltmeter is thus $1{\cdot}438\,\frac{a\,c}{a\,b} \times \frac{\mathrm{L} + t}{t}$. This diagram is taken from Prof. Fleming's article in *Industries*, of March 4th, 1887; but the disposition is altered, as in Prof. Fleming's arrangement the galvanometer is so connected that the least leak throws the whole of the measurements wrong. Prof. Fleming's arrangement depends for its success on the perfect insulation of all the parts of the apparatus. There is no real advantage in putting the potentiometer in a separate circuit, as the sensitiveness is not perceptibly increased. On the other hand, it is more costly and more complicated. The contact springs at *b* and *c* should have ebonite press buttons, as the finger will be at a higher or lower potential of a volt or two. Of course G and G′ are the same galvanometer. The connections may be led to mercury cups in a block of paraffin. Blocks of paraffin, though they look untidy, and are not often used, are very handy, as the insulation is perfect, and if they get dirty a little of the outside can be pared off. The addition of resin is an improvement.

The arrangements which involve the use of a potentiometer have been described here because Prof. Fleming, who has given considerable attention to the subject, advocates its use; but it would seem much simpler and much more accurate to remove the whole of the arrangements forming the lower part of fig. 44, and to put a standard cell with key and galvanometer in shunt to *t*, so that the arrangement becomes as described on page 78. The electromotive force on the voltmeter is then got volt by volt, which is an advantage. An adjustable resistance must be put in circuit between D and P. The resistances, L, may be made up in the ordinary way, but the wire should not be wound double, as self-induction gives no trouble when cells are used and insulation is important. It is important that the coils should keep cool. Mr. Ashley, who has charge of the manufacture and calibration of Messrs. Crompton & Co.'s instruments, uses a number of coils wound on ebonite bobbins with a pair of copper terminals sticking out at one end. A block of solid paraffin is made with hollows which serve for mercury cups. The coils are placed on the block of wax so that the terminals of each dip into neighbouring cups, and when a coil is removed it is replaced by a short-circuiting loop of stout wire. The coils consist of 20 bobbins of 1,000 ohms each.

If the instrument to be calibrated contains iron it must be calibrated upwards, as persistent magnetism errors would otherwise throw the readings out. This makes it difficult to arrange the resistances, L, so as to avoid temperature errors. If the high readings are taken first, the resistance coils may all be allowed to get as hot as they will first, and as the current through the resistances is practically constant, no error will creep in as the coils are merely put out of circuit one after the other. In calibrating upwards, however, cold coils have to be added successively. The best method is to make the resistances high and ventilate the coils. Of course no errors arise from the temperature of the room, as the ratio of *t* to L remains constant. When *t* is a fixed resistance, and L a set of coils, the temperature error due to the variation of electromotive force of the standard cell makes a correction for temperature necessary. This difficulty may be overcome in several ways. A small stretched wire may be inserted between *t* and L, so that by moving the contact, B, along it, the temperature error may be almost exactly corrected. This wire resistance is so small in comparison with *t* that any unevenness in the wire causes no perceptible error. Perhaps the best way is to wind the coils of L with wire with a higher temperature coefficient than that used in *t*. Thus each of the coils of L may be partly of German silver and partly of copper, while *t* is entirely German silver. The amount of copper used depends on the temperature coefficient of the particular sample of German silver used. This does not give a solution of the problem mathematically correct, but for practical work it is near enough, as it is within one in two thousand when an instrument is calibrated from 100 volts down to 10. The arrangement is thus direct reading, a point of great importance in practical work.

If the arrangement in fig. 44 is used, it can be made direct reading by putting *b* on the mark 1438 or some simple multiple of it, so that *c* reads the electromotive force of the voltmeter. If L is not 99*t*, of course another figure must be used to make the potentiometer direct reading.

The methods of calibrating voltmeters, described above, are suitable for makers of instruments, and most electrical engineers are in want of some more simple means of checking a voltmeter or ammeter to see if it is approximately correct. Most engineers have a Wheatstone bridge, generally of the Post Office pattern, a horizontal detector, and some voltmeters and ammeters.

It would be absurd to set up a set of little cells and make a number of carefully-measured resistances to see if the voltmeters and ammeters are correct. The first thing to do is to see if the voltmeter agrees with the ammeter. Suppose the voltmeter reads up to 120 volts, and the ammeter up to 50 ampères. A wire which will carry 5 or 6 ampères without heating perceptibly is taken, and, say, 200 ohms of it measured off. This is divided off into 10 equal lengths. If the wire is uniform, each of these will be 20 ohms. The 10 wires are soldered up in parallel, so that their resistance is 2 ohms. If there are any slight errors due to the unevenness of the wire, the error will be small with the 10 coils in parallel, but, if the time can be spared, it is best to measure the 10 pieces, and cut them off at 20 ohms each. The voltmeter is put in shunt to the resistance of 2 ohms thus made up, and the ammeter is put in series with them. The error caused by the current through the voltmeter going through the ammeter is too small to be considered. A dynamo is then switched on and readings are taken. As the electromotive force and current from a dynamo cannot be varied much, the electromotive force on the arrangement may be reduced by inserting resistances in series at random. If at all the readings the electromotive force as read on the voltmeter is twice the current as read on the ammeter it may be safely concluded that the instruments are correct. If the readings do not agree properly, and the resistances are measured carefully, either the voltmeter or ammeter is wrong or both are out. If the wires, which make up the resistances, heat, so that their temperature rises, this may cause a small error, but this can be avoided by letting the whole cool before taking each reading, or by taking a piece of the same size of wire and measuring its resistance cold, and after the current has been passing for some time and then allowing for the error. Of course, if the readings agree the instruments may be wrong, as one may read too high, and the other too low throughout, but this is very unlikely. A dynamo does not give as steady a current as secondary cells, but if the commutator is in good order, and if the brushes are set so that there is no sparking, there will be no perceptible error due to unsteadiness, especially if the commutator has many sections, and if the brushes have little lead.

If a voltmeter is to be checked, all that is wanted, besides a bridge and a galvanometer, is a few ounces of fine wire, and a standard cell, which costs thirty shillings.

The arrangement is shown in fig. 45. The dynamo, D, takes the place of the little cells. The resistance, R, is about 10 times that of the voltmeter; and is adjustable, that is to say, it can be short-circuited out bit by bit so as to increase the electromotive force on the voltmeter as desired. In most cases, however, it will be found impracticable to make an adjustable resistance 10 times that of the voltmeter, and the electromotive force can then be partly regulated by putting some resistance in series with the voltmeter and some in shunt as shown at *r*. The simplest form of adjustable resistance is a bare wire coiled in spirals, and provided with a clip for short-circuiting out as desired; L is a coil of fine wire of, say, 10,000 ohms. All that is necessary is to order, say, 1 ounce of No. 36 B.W.G., or 2 ounces of 35 B.W.G. German silver wire from the makers, wound on a bobbin with both ends accessible, or a corresponding weight of platinoid. Before use the coil should be left for some

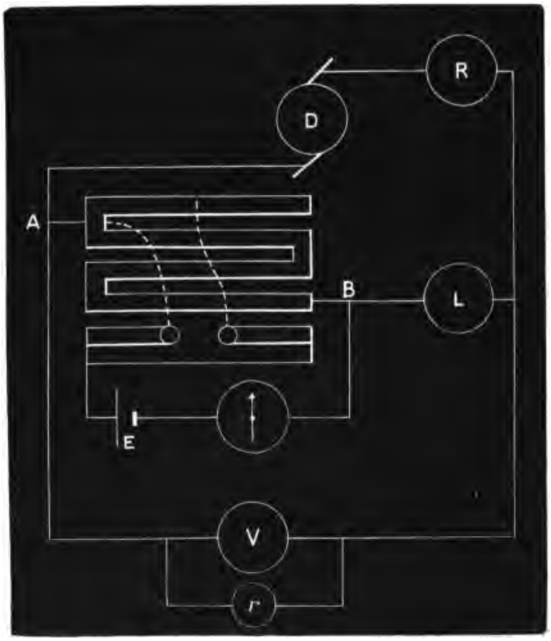


FIG. 45.

weeks on the top of a boiler, or it may be boiled in paraffin. The resistance is then measured. The resistance part of the bridge is put in series with the coil, and the standard cell and galvanometer are in shunt to the plug resistance. The left hand key makes contact direct, and the right hand puts 1,100 ohms in series with the galvanometer to protect the cell from excessive current. If the electromotive force on the voltmeter is 100 volts, and if L is about 10,000 ohms there will be about 150 ohms drawn in the resistance box to balance the electromotive force of the standard cell. As this resistance can be altered ohm by ohm the upper part of the scale can be calibrated within ·6 per cent. Even this can be subdivided by noticing how much the galvanometer needle deflects each way. Thus, if with 120 ohms drawn, the galvanometer needle deflects 12° one way, and if with 121 ohms it deflects 4° the other, it would balance at 120·75 ohms. Of course this is not good for the cell. It is best to have an ohm of wire stretched between L and the bridge, B being a sliding contact.

It is better to put the resistance box in shunt to the standard cell as shown, than to put the whole electromotive force of the dynamo on it, as that may be apt to injure the bridge. The arrangement is not direct reading of course, but if only one or two instruments are to be calibrated that is of no consequence. The electromotive force on the voltmeter is, of course, $\frac{1{\cdot}438 \times (\text{L} + t)}{t}$, t being the resistance between B and A.

If the detector is fairly good and has a resistance of 250 ohms or so and a free needle, it will be found that this apparently rough method of calibrating is quite accurate enough for checking instruments within 1 per cent. or so. Care must be taken not to let the coil, L, get hot. Care must also be taken not to couple the standard cell backwards, and not to put the left-hand key down till the resistance is adjusted as nearly as possible with the right-hand key. If the cell is coupled up backwards it will be found out at once by its always deflecting the galvanometer the same way whatever the resistance drawn. At first, if there is any uncertainty, the right-hand key should only be touched down for a moment at a time. If the galvanometer does not prove to be sensitive enough, it is probably because there is some friction at the pivots. If it can be got, an instrument with a suspended needle is of course better.

CHAPTER VII.

CALIBRATION OF AMMETERS.

Ammeters are generally calibrated with a standard cell or by electro-deposition. If a standard cell is used the current through the ammeter is passed through a low resistance which is accurately measured, and the fall of electromotive force is measured, so that the current is known. As in the case of the calibration of voltmeters the ways of arranging the apparatus are very numerous. The chief difficulty lies in making a low resistance which can be accurately measured and which does not alter too much in resistance through heating. The resistance can be made up of a large number of coils of German silver or platinoid wire, preferably of platinoid, because if the wire has a certain surface per ohm, it will rise to the same temperature whatever the specific resistance of the metal, and for a given rise of temperature platinoid, as it is called, gives the lowest temperature error. A small wire that will carry 1 ampère without rising perceptibly in resistance is chosen. The resistance may be so arranged that it remains constant, and the current through it is varied so that the fall of potential varies. The fall of potential is then measured each time, or the resistance may be varied so that the current in each wire is always the same, so that the fall of potential is the same. This is the best method. Suppose the ammeters run from 1 up to 1,000 ampères, a number of groups of pieces of wire are arranged. One group consists of one wire only of a resistance of, say, 2 ohms. The next has two wires of 2 ohms each in parallel so that with 2 volts 2 ampères pass and so on, the groups consisting of 1, 2, 2, 5; 10, 20, 20, 50 wires, and so on. In the case of groups of 20 or more wires, it is not necessary to measure each wire separately; if the wire is fairly well made, a piece measuring 400 ohms can be carefully measured off and divided up into 20 equal lengths. Neighbouring coils should be wound in opposite directions, so as to neutralise each others' effects on any instruments near. The coils for 1,000 ampères thus form a set of 12 groups of coils, which, if 2 volts are kept on them, will give currents varying from 1 to 1,000 ampères by steps of only 1 ampère at a time. A larger wire capable of carrying, say 10 ampères, may be used for the third set, as it would be expensive to make up 1,100 spirals of small wire. The wires of each group, especially in the case of the large groups, are connected by thick copper bars of no perceptible resistance. These are all connected together at one end, at the other mercury cups are arranged so that the groups can be put into or out of circuit as desired. The mercury connections may be made by copper loops, but copper is apt to become amalgamated. Iron may have enough resistance to produce a perceptible fall of potential, so it is best to use copper well nickeled, as nickel protects the copper from mercury.

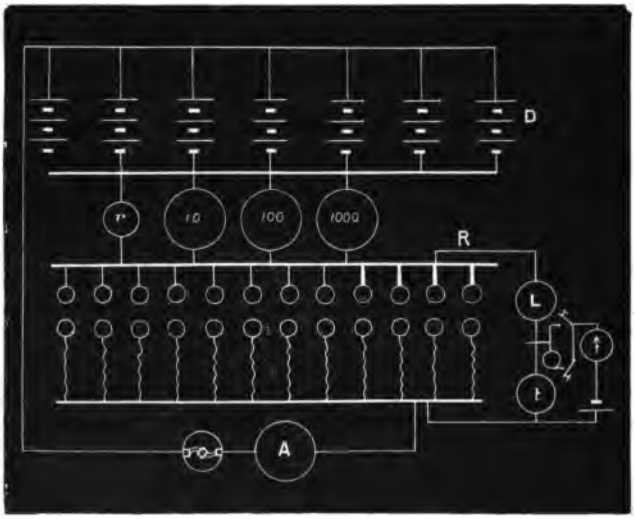


Fig. 46.

Figure 46 is a diagram of the arrangement. D is a set of secondary cells capable of giving 1,000 ampères and, say, 6 volts. The fall of electromotive force over bad contacts in switches, &c., is astonishing, and though only two volts are needed on the resistances, it is as well to have six or so at command.

The cells discharge through a set of regulating coils. These may consist of eight or twelve sets of coils on the same principle as the standard resistance, but not measured, and made without care as to rise of temperature beyond avoiding excessive heating. Instead of mercury cups, plugs or switches are used. Though this arrangement is simple, it cannot be worked very rapidly. What may be called a conductivity switch is shown in fig. 47. The first puts in a maximum resistance of 1 ohm. It has ten contacts, so that at the last it only has $\frac{1}{10}$th ohm in, so that the conductivity is 10. It never short-circuits altogether, of course. On the next contact there is $\frac{1}{9}$th ohm in, and so on,

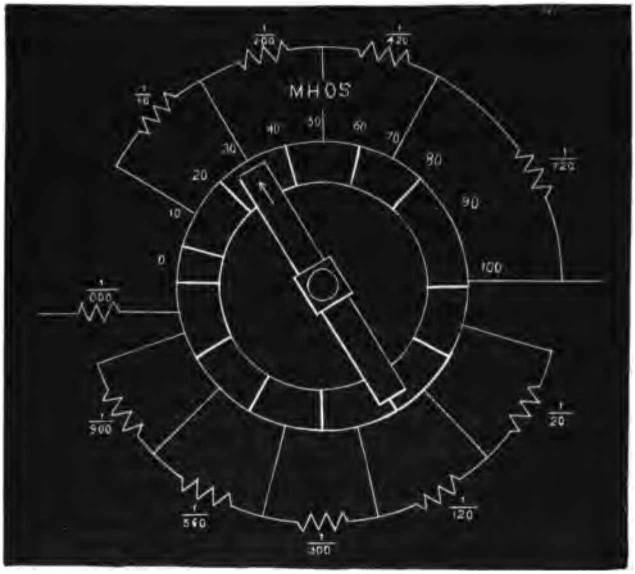


FIG 47.

so that it varies the conductivity from 1 to 10 mhos. The next is from 10 to 100 mhos, and is that shewn in fig. 47, and the third is from 100 to 1,000 mhos. There is a rheostat, *r*, which is of, say, 2 ohms, with range down to half an ohm. The current can thus be varied from 1 to 1,000 ampères perfectly gradually. The conductivity switches are on the same principle as the crossbar switches described for putting resistance in series with voltmeters when calibrating them. The contacts should be very good, the cross-bars being made of stencil copper bent down so as to make good contact and allow the switch to be turned either way. Conductivity arrangements are generally made to put varying numbers of coils in parallel. In this case the coils are in series, but the same effect is obtained with much quicker manipulation.

This particular calibrating arrangement is troublesome, because it involves so many resistances; but that is because it has such a long range. Without the third set of coils it would calibrate up to 110 ampères; it is then simple, accurate, and inexpensive. For very large currents some of the arrangements to be described later are, perhaps, preferable.

The standard cell is coupled up as shown in shunt to the resistance, *t*, fig. 46, which is a coil of well-insulated wire whose resistance has been measured. The resistance, L, is in series with this. The ratio of the resistance is 1438:562, so that when there are two volts on the standard resistance the galvanometer is not deflected. A safety resistance is put in series with the galvanometer as usual. The keys are close to the adjusting switches or plugs so as to be handy. The resistances, L and *t*, may have different temperature coefficients so as to compensate not only for the temperature errors of the standard cell, but for the temperature errors of the standard coils also.

To calibrate an ammeter it is put in circuit as shown. The standard resistances are arranged for the lowest current wanted, say, for 10 ampères. The adjusting switches or plugs are then arranged till there is no deflection on pressing the resistance key, the final adjustment is then made by means of the rheostat, *r*, the other key being used. The instrument, A, is thus calibrated directly, ampère by ampère.

If the standard resistances heat, or if they are suspected of alteration, the resistance can be taken by one of the methods described under the head of measurement of low resistances. Heaviside's will be found the most convenient if a differential galvanometer is at hand.

A small piece of stretched wire may be left between the coils L and *t*, so that if the standard resistances are at any time found to be a little out the error may be corrected by moving the contact a little. This may also be used for corrections for temperature of the cell, the right positions on the slide being marked in degrees, and a thermometer being inserted in the cell.

It must not be forgotten that the current through the coils, L and *t*, goes through the ammeter; but it is so small in comparison with the large currents used that it may generally be neglected.

The chief fault in the arrangement last described for calibrating instruments for very large currents, such as 1,000 ampères, is the large number of spirals of wire made so small as not to heat, or at least not to rise in resistance perceptibly.

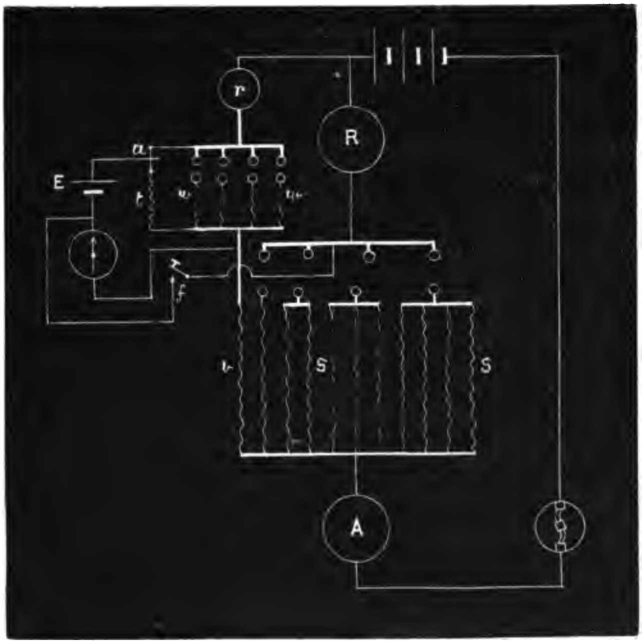


Fig. 48.

The arrangement shown in fig. 48 gets over this difficulty to a large extent, as the readings do not depend for their accuracy on the absolute resistance of the coils. This arrangement needs two adjustments, however, but as these can be made very quickly, the disadvantage is small in comparison with the saving in expense in making up the apparatus. Taking 100 ampères as the maximum current first, 10 resistance spirals, *s*, *s*, are made up of the same resistance. It does not matter what the resistance is, but ·1 or ·2 ohm will do very well. These resistances are made of the same wire and of the same dimensions, so that they all heat equally. The heating may, therefore, be neglected, so that the wires need only be large enough to carry the current without getting too hot. Nine or 10 spirals are arranged in the main circuit with the adjusting switches, R, as in the former case. Another spiral, *v*, is on a separate circuit with its own adjusting switches, *r*, and a set of small spirals, *w*, *w*. These are carefully measured. The highest is 1·5 ohm or so, and the rest have conductivities in the order of 2, 3, 4, so that the four altogether have 10 times the conductivity of the first alone. Thus 1·5 volt on this set of resistances will give 1 to 10 ampères through the thick coil, *v*. If the standard cell had no temperature error the first coil would be 1·438 ohm and so on, but 1·5 is taken to allow for correction. The standard cell, E, is connected up as shown, so as to be in shunt to part of one coil of 1·5 ohm, but the press contact can be moved so that 1·5 volt on the resistance can be balanced, whatever the electromotive force of the cell may be at the temperature it is used. It must not be forgotten that this makes a fifth resistance which is always in circuit, so that when all the resistances are in parallel, 11 ampères pass, not 10.

The large coils may be coupled up in four sets, so as to range from 1 to 10 in parallel. The connections may be made by means of plugs, or by mercury cups and nickeled copper connections, the latter plan being the best, though not the neatest.

This arrangement, which has only eight adjusting coils altogether, does not admit of calibrating from 1 to 100 ampères, ampère by ampère, as the ampères must always be the product of two numbers, each less than 11 or 12. Thus 71 ampères cannot be got, but 70 is got by having seven thick spirals in parallel, and the resistance, *w*, arranged for 10 ampères, or the resistances, *w*, *w*, may be arranged for 7 ampères, and 10 spirals may be in circuit. To get 72 ampères, seven spirals are put in parallel, and the resistances, *w*, *w*, are arranged for 6 ampères. The rheostat, *r*, is then adjusted till there is no deflection on touching the contact, *a*. The rheostat, R, is also adjusted till there is no deflection on pressing the key, *f*; and the reading is then taken on the ammeter. For all practical purposes, this arrangement gives sufficient data for graduating an instrument, and it is not expensive to make.

By a slight modification it may be made to give more frequent readings.

The object of the arrangement is, of course, to avoid the necessity of measuring the low resistances, s, s, and of making it of such large wire that it does not rise. This is done by measuring the current in one of several small coils. The idea is taken from Mr. T. Gray.

If the standard resistances are made to take from $\frac{1}{10}$th to 10 ampères, the current through the ammeter can be increased ampère by ampère from 1 to 100. s, s, may then be 9 coils in parallel without plugs or mercury cups. If the large coils are made large enough to carry 100 ampères each, and if the standard resistance takes from 1 to 100 ampères, the arrangement will do for 1,000 ampères. The standard resistances, *w*, *w*, for 100 ampères with 1·5 volts are then 1·5, ·75, ·5 and ·375 for the first, and ·15, ·075, ·05 and ·0375 for the second. These resistances may be made up of coils of wire of 1·5 or ·15 ohms arranged in parallel. There are thus only 12 adjustment coils in the whole arrangement. This does not actually go up to 1,000 ampères, ampère by ampère; for instance, after 700 the readings go 710, 720, &c., but intermediate readings which are products of numbers up to 100 by numbers up to 10 can be got, though they are hardly necessary. Thus, 702, 704, 707, 711, 712, 714 can be got, and such combinations are useful checks.

The fall of potential over the standard resistances, *w*, *w*, may, of course, be measured by a potentiometer or a set of resistances if the potentiometer is not considered accurate enough. This generally necessitates a local circuit and some complication.

This is perhaps the simplest way of calibrating with large currents using a standard cell.

In many cases it is preferable to calibrate ammeters from a standard instrument. If the standard instrument can be depended upon, this is the most expeditious way. The standard instrument may be of one of Sir William Thompson's balances or an instrument with a permanent controlling magnet. A skew tangent instrument is very useful for this purpose. If the instrument is of very low resistance and reads, say from 1 to 10 ampères with accuracy, it is merely inserted in series with one of the large spirals without any special rheostat. The spiral is made so that with the instrument in series with it, it is of the same resistance as one of the other spirals; the difference of the rises of resistance of the coils when in use is quite inappreciable.

Messrs. Goolden & Co. use a very good method devised by Mr. Evershed. An instrument is made which shows when one ampère is passing. This is put in series with a resistance, and there are many more resistances exactly equal to it which can can be put in parallel. So that if 12 ampères are wanted 11 of these resistances are put in circuit and the whole current is regulated till the ammeter index comes to the mark. An ammeter to be calibrated is thus tested, ampère by ampere, without any fractions. The standard instrument is made so that a division of $\frac{1}{10}$th per cent. causes considerable deflection. This is perhaps the most accurate way of calibrating from a standard ammeter, as the other methods are limited by the possibility of reading the scale of the standard.

The standard instrument must be carefully calibrated throughout its scale to begin with, and must be checked every month or so to make sure that the controlling magnet, if there is one, is not weakened at all. If it is weakened the magnet must be moved closer to the needle, or the deflecting coil must be moved further from it. The standard instrument may be calibrated to begin with by making up a special resistance and working from the standard cell, or by deposition, as will be presently described.

So far most of the arrangements described have given currents increasing ampère by ampère, the main current being altered by resistance till it is the required number of ampères.

In Prof. Fleming's arrangement, which will now be described, the current is altered by a resistance to any approximate value, and this value is measured by means of a potentiometer. The arrangement has frequently been described, so it will be unnecessary to discuss it very fully.

A number of spirals of brass wire are carefully measured, and are then arranged on a frame with mercury cups and bars, so that any number of spirals can be put in parallel. On moving a handle they are put in series. The resistances are carefully measured separately, and their conductivities are marked, The spirals are arranged so as to give the current required with a convenient fall of potential, and the electromotive force is measured by means of a standard cell and potentiometer. If the resistances heat and thus alter, they are thrown in series and measured. This arrangement has been in use at Messrs. Crompton's works for some time, and works well; it is a little complicated and expensive to fit up, however, but it is easy to work with if the calibration is not done ampère by ampère. A full description of Prof. Fleming's arrangement will be found in *Industries* of last year.

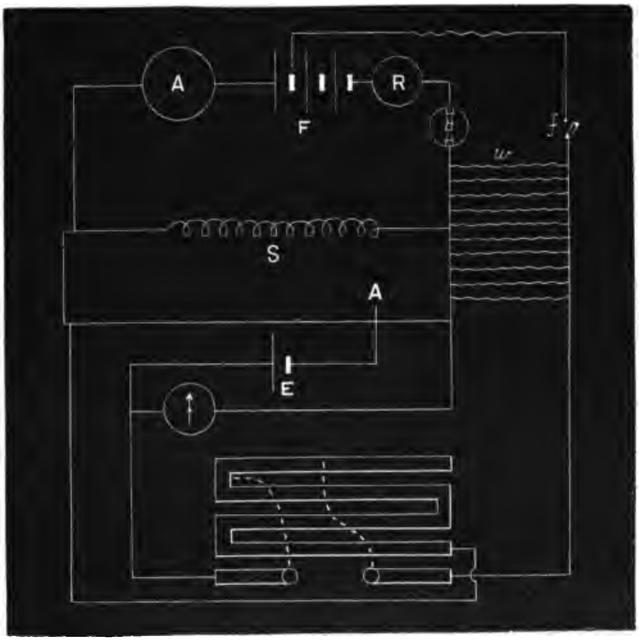


Fig 49.

For merely checking an ammeter—as, for instance, when an engineer has bought one and wants to see if it is correct, it would not be worth while to make up complicated resistance frames. The methods by electro-deposition need considerable care, and are not useful unless a chemical balance is at hand.

Fig. 49 shows a simple arrangement for roughly checking an ammeter. The instruments assumed to be possessed are a galvanometer, a standard cell, and a resistance bridge. The current through the ammeter to be calibrated goes through a wire resistance which is made up at random, and this resistance is measured hot, just after the current has ceased. Suppose the instrument to be checked reads from 20 to 100 ampères, a resistance is taken which is at least ·075 ohm, so that 20 ampères give 1·5 volts or so. This may be a coil of cable or some iron wire, or an armature of a dynamo machine which is not running. It must be capable of carrying 100 ampères without excessive heating, and it is rather an advantage if it does not lose its heat quickly. This is shown as S in the diagram. As the bridge of the resistance box is not likely to contain a resistance comparable with ·075 ohms, and as contact errors would give trouble if it did, a special resistance must be made up of, say, ·1 ohm. To do this 10 ohms of platinoid wire are measured off, this is cut into ten equal lengths, and these are soldered to two stout copper bars, thus making a resistance of ·1 ohm. If greater accuracy is preferred, ten wires of 1 ohm each may be separately measured. In measuring allowance must be made for the length taken by the soldering. The wire should be so long, that the length taken by the solder is inappreciable in comparison, or, say, a quarter of an inch at the end of each piece must be allowed, so that 5 inches are added to the 10 ohms before dividing up, care being taken that the soldering takes up half-an-inch of each piece. This standard resistance is shown at *w*. The standard ·1 ohm resistance is coupled in series with the large current resistance as shown. In shunt to the large current resistance a potentiometer is arranged. This may consist of a piece of German silver or platinoid wire, and may be, say, 4 feet 2 inches, or 100 half-inches long. A scale in half-inches can be made of paper and put underneath. The large current resistance is shown in the diagram, as if it were stretched along the table; in practice it will probably be some little distance away. The leads to and from it must then be considered part of the resistance, and the potentiometer must be arranged in shunt to them, also as shown. To take a reading, enough of the cells F are put in circuit to give about the reading desired. The contact A is touched down till the position is found where there is no deflection, and the position and the reading on the ammeter are noted. The large current is then stopped, and a small current sent through the standard resistance and large current resistance by closing the switch *f*. The 100 ohm plug is drawn on the left hand side of the bridge. Plugs are drawn till a balance is obtained on pressing the keys. Suppose the balance to be obtained with 77 ohms drawn, and suppose the potentiometer reading to be 30. Then the resistance of the large current coils is ·077 ohms, and the electromotive force on it is 1·438 × 100/30 = 4·79 volts, so the current was 4·79/·077 = 62·2 ampères. The resistance measured is, of course, really that of the large current resistance and potentiometer in parallel. Instead of one potentiometer wire, two or three may be used in parallel, contact being made on one after the other. If the position of no deflection is the same on all, it may be assumed that the potentiometers are correct.

If secondary cells are not at hand a dynamo may be used as a makeshift. In that case the large resistance should be made with as little self-induction as possible, and the dynamo should have its commutator in good order, and should have a large number of sections. The current used for measuring the resistance should, of course, be small.

So far it has been assumed that the calibration is done from standard cells. Many prefer to use voltameter methods. In this case a standard instrument is calibrated by deposition, and the instruments sent out are calibrated from it, as it would be too tedious to calibrate commercial instruments throughout their scales by deposition methods.

A silver or copper voltameter is always used. Of these, the silver voltameter is used when very accurate results are desired; but for most practical work the copper voltameter is preferable. The silver voltameter needs more care to make it give results of the highest accuracy, while the copper voltameter, which does not under any circumstances give such accurate results, is sufficiently correct for commercial work, without demanding such special care in use.

The different kinds of standard cells recommended by different authorities have been numberless, but the Clark cell is now generally considered the most accurate, and it has been assumed in this book that that standard is used. Many prefer to make up their own standards.

The standard Clark cell consists of mercury in contact with mercurous sulphate, and zinc in contact with zinc sulphate. The mercury should be pure. Messrs. Becker & Co. keep an apparatus for re-distilling in vacuo, so the mercury can be got from them. Reputed pure mercurous sulphate, and pure zinc sulphate and pure zinc, can be bought from any of the well-known chemists. The mercurous sulphate is boiled several times in distilled water to wash it. Messrs. Wright and Thompson pour the mercury hot and recently distilled into the cell, and then pour in a hot thin paste of mercurous sulphate and saturated hot solution of zinc sulphate. The zinc sulphate crystallises on cooling, and makes the paste partly solid. When the mercurous sulphate has settled the extra solution is drawn off by a pipette. The zinc rods are brightened by glass paper, and are washed with ether, alcohol, and the zinc sulphate solution successively before immersion in the paste. A copper wire is soldered to the zinc rod, the joint being coated with gutta-percha. The zinc rod is held in position by a slice of cork boiled in paraffin. Messrs. Wright and Thompson make connection with the mercury by using a U-tube as the cell, one leg being quite small, so as to admit a platinum wire only. An ordinary German glass test tube will do, and the mercury connection can be made by leading a small platinum wire through a small glass tube sealed over it, so that only a short piece touches the mercury, the end of the glass passing below the surface of the mercury. The electromotive force of the cell is 1·435 real volts at 15°, according to Lord Rayleigh, or 1·438 legal volts. The electromotive force falls as the temperature increases. Messrs. Wright & Thompson give 0·041 per cent. per degree C. as the co-efficient. Lord Rayleigh and Helmholtz have given a higher figure, ·082, and Pellat, by inserting a thermometer in the cell itself, finds ·0781 per cent., so that ·08 is probably about right.

It is strange that such good results can be got from Clark's cells. Mercurous sulphate can hardly be made really pure. As bought it is grey or greenish grey, and often turns yellow on shaking with water. Even if not mixed with turpeth mineral or mercuric sulphate, a basic mercurous sulphate is formed. There appear to be six sulphates of mercury, and the bought mecurous sulphate is probably a mixture of several with, perhaps, some oxide also, especially if the salt has been exposed to light. Mercurous sulphate prepared by the writer by one method was white, by another greyish. Pure zinc sulphate reddens litmus, and zinc carbonate is therefore sometimes added. This makes a basic zinc sulphate. The subject deserves further investigation.

Standard cells should not be used for a week or so after being made up. Dr. Muirhead has brought out a standard cell in which there is no mass of mercury, so that it can be sent about without damage. He uses an amalgamated platinum wire. The wire is curled up into a flat spiral, heated red hot, and plunged into mercury, which then amalgamates it superficially. Dr. Muirhead makes up a pair of cells with an enclosed thermometer, having its stem bent over the top of the case, so as to read horizontally. These cells can be obtained from Messrs. Muirhead & Co., of Cowley Street, Westminster.

Any number of different forms of standard Daniell cell have been proposed, and this is a strong argument against the use of any of them. The best form is probably that of Prof. Fleming. This consists of a U-tube, with means of drawing off the solutions at the point where they meet, so as to prevent error from diffusion. This cell has been frequently described in electrical papers. The chief advantage is the small temperature error; and the cell is probably less influenced by giving a small current.

Lord Rayleigh has tried short-circuiting Clark's cells through various resistances, but nothing is said about passing currents backwards. A cell accidentally short-circuited through even 1,000 ohms for several minutes recovers practically in a quarter of an hour.

Little has been said about calibrating ammeters by deposition, because the methods by resistance and standard cells seem more reliable. In the hands of very careful experimenters silver or copper voltameters may be used.

For copper deposition, Mr. Gray, who has gone into the matter very thoroughly, finds the cathode or gain plate should be of such a size that it has about 20 square centimetres to the ampère, or a somewhat greater surface. The cathodes or gain plates may be made of thin copper. The edges should be rounded off, and the surface cleaned and polished with silver sand, then well washed and dried on blotting paper, and warmed. They are then ready for weighing. They must be allowed to cool first, of course, otherwise a large error would be introduced. Care must be taken not to touch the cleaned plates with the finger, as it is always to some extent greasy, and the deposit would be bad, showing a finger mark. The plates, both anode and cathode, should be made of pure copper. What is sold as pure copper is generally electro-deposited. Electro-deposited copper may be pure, but it seems rather a bold assumption. It is generally supposed that a metal must be pure because it has been electro-deposited; but there is no reason why this should be taken as certain.

The solution should be made of a density of about 1·1 to 1·2, distilled water and pure copper sulphate being used. The solution should be slightly acidified with sulphuric acid. Mr. Gray finds ·000329 gram per coulomb the constant when the gain plates have an area of 50 square centimetres per ampère. It is best then to adhere to this current density. This is equal to 1·1844 gram per "ampère hour." For further information relative to copper deposition the reader is referred to Mr. Gray's paper in the *Philosophical Magazine* for November, 1886. An abstract of his British Association paper in the same year appeared in the electrical papers.

For silver voltameters, Lord Rayleigh prefers to deposit the silver on the inside of a platinum bowl. Mr. Gray, on the other hand, prefers plates. The great difficulty in silver deposits is the washing and management of the gain plates. The deposits are apt to be very loose, and little crystals tumble off if the greatest care is not taken.

The silver plates should be cleaned in the same way as the copper gain plates. The solution used should be about 5 or 10 per cent., that is 1 ounce to 2 ounces of silver nitrate to the pint of distilled water. Lord Rayleigh prefers a 15 per cent. solution. The plates should have an area of from 200 to 600 square centimetres per ampère. Still greater care is necessary in cleaning the gain plates, as the least thing will make the deposit loose. Distilled water must, of course, be used for washing the plates. Hard water would deposit silver and calcium compounds among the crystals of the coating. Lord Rayleigh gives ·001118 as the silver deposited by a coulomb, or 4·0248 grams per ampère hour.

CHAPTER VIII.

DYNAMOS AND MOTORS.

Dynamos and motors have to be tested as to their output, electrical and gross efficiency, and compounding, or constancy of electromotive force.

Motors and dynamos will be treated together, as a motor is simply a dynamo with some of its conditions reversed, and follows the same laws and principles of design. There are still, no doubt, a few makers who hold to the old fallacy that a dynamo should have a strong field and few ampère turns on the armature, while a motor should have a weak field and many ampère turns on the armature. This idea is based on the theory that in a dynamo the armature current weakens the field or lessens the induction through the armature, while in a motor it increases it. This reasoning is fallacious, as the armature current in a motor also lessens the induction in the armature unless the brushes are given a lead in the wrong direction. If the brushes are given a lead in the wrong direction, the induction is increased in a dynamo and in a motor, but the machine sparks and wears out the commutator and brushes.

Of course, if a light motor is wanted, it is not designed like a heavy but efficient dynamo, but the design of the light dynamo does not differ from that of a light motor in any respect. The interchangability of dynamos and motors was first formally published by Mr. Mordey, but even now these points cannot be too fully discussed, as many engineers still adhere to the old theories, and when they have to superintend an installation for electric transmission of power, they put down motors made on the principle that the worst possible dynamo is the best motor.

Dynamos are generally made of one of four classes, 50 volts, 100 volts, arc lighter, or electro-deposition machines.

For testing work it is best to run the machine off into resistances. Secondary batteries might be used, to save power, but as only shunt machines could be run off into them, they would not pay. A motor can also be used to absorb the power and give a percentage back to the countershaft; but the cost of the motor and the troubles and complications make that also out of the question.

The test room of a dynamo works, or of any establishment where machines are tested, must be provided with resistance frames which will take the largest currents wanted. The resistances may be made capable of carrying, say, 1,000 ampères. This with 100 volts requires an engine indicating from 170 to 200 H.P., which is greater than is generally available. The resistances are generally made up so that a larger or smaller number of spirals of wire can be put in parallel. Each spiral must therefore be able to take 100, or perhaps 150 volts on it without heating excessively.

The mho switches described for regulating large currents in the calibration of ammeters and illustrated on page 93, are very suitable. For currents of from 1 to 1,000 ampères, only three switches are required. The first gives ·01 to ·1 mho, that is, from 100 to 10 ohms, so that if the machine gives 100 volts or so, this switch regulates the current ampère by ampère. The next switch is from ·1 to 1 mho, thus regulating the current by tens of ampères. The third is from 1 to 10 mhos, thus regulating the current by one hundred ampères at a time. The first resistance is half an ohm; as this is in when the switch is at 1 mho, it has to be capable of taking 100 ampères. The next resistance is $\frac{1}{6}$th ohm, which is in circuit when the switch is at 2 mhos. This must be able to carry 200 ampères, and so on. The denominator of the fractions representing the resistances in a mho switch, run in progression 1×2, 2×3, 3×4, and so on up to 9×10, or $\frac{1}{90}$th of an ohm. The resistance which is left last, and is never taken out is, of course, $\frac{1}{10}$th, or 10 mhos. These resistances must be able to carry currents of 100, 200, 300 ampères, and so on. If there is not power to run off machines giving 100 volts and 1,000 ampères, the last spirals may be made smaller. For instance, if 100 volts and 250 ampères, or 50 volts and 500 ampères are the maximum loads, the spirals after 3 mhos may be made to carry 150, 200, 250 ampères, and so on, as there will never be 100 volts on them. It is best, however, to make the coils large enough to take large currents, as they will then be available for machines giving outputs at electromotive forces up to, say, 200 volts.

The resistances should not be made of spirals of iron wire, as iron is circularly magnetised, and the self-induction soon destroys switches. If spirals are used they should be alternately right and left handed, so as not to affect instruments. Probably it would pay best in the long run to use carefully measured platinoid wire resistances throughout, as that admits of measurement of large currents by means of a voltmeter put across the resistance terminals. If this is not always used, it is always an available check on the ammeters.

To prevent the burning of the switches used for breaking circuits when the currents are large, it is a good plan to arrange a lead fuse in shunt to the switch. The switch then shows no spark, the circuit being really broken by the fusion of the lead wire. Series machines should never have their circuits suddenly broken. To stop the machine the field should be short circuited and the main circuit opened when the field is lost. Otherwise the induction shock is apt to damage the insulation of the field magnets.

For arc light machines a separate set of resistances taking 15 to 20 amperes is required. These need not have mho switches, but may be merely arranged in series. One switch cuts out resistance ohm by ohm, and another 10 ohms at a time. A third goes by steps of 100 ohms at a time up to the highest resistance required, 300 being probably the outside. This set of resistances should be very well insulated.

For electro-deposition machines giving from 5 volts upwards a fourth, and perhaps a fifth, switch may be added to the 100-volt set. These are from 10 to 100, and from 100 to 1,000 mhos. The great trouble with these low volt machines arises in the leads and instruments. It is exceedingly difficult to work with a large current and 5 or 6 volts, as the whole of the electromotive force is apt to be lost in the leads, switches and instrument connections. The resistances for these large currents may be made of spirals of wire. Strips of lead immersed in a tank of water are very useful for this sort of work, and work well even up to 50 volts. The writer has not tried them with 100 volts, but there seems little reason to suppose they will not work. The rate at which lead strips will get rid of energy in water is very surprising; and these resistances are very cheap to make. Of course other metals will not do, as one end acts as an anode and the other as a cathode.

Mercury cups may be used for connections in large current work, but they are untidy, and the mercury is often spilled and lost and is expensive. An amalgam of mercury and copper is very handy. It is soft and pasty, but sets hard, becoming soft and pasty again when hammered or rubbed in a mortar. It can be made by electro-depositing copper into mercury.

The resistance arrangements just described may not be sufficient for all purposes, as it is often necessary to separately excite a machine. If the machine is wound with a fine shunt wire the arc resistances may be used. It is then as well to have them adjustable by tenths of an ohm, so that there are four switches. For separately exciting machines of new types wound with large wire for experiment, the large resistances may be used, but that does not admit of taking full load readings. A spare set of resistances is therefore a great advantage.

The first thing to test is the resistance of the shunt circuit, main circuit and armature. The methods of taking very low resistances have already been described.

The machine should also be tested for insulation, care being taken to see that there is no leak to the frame from any part of the circuit, or from the shunt and the main wires. Insulation tests should be taken, as already pointed out, with the full electromotive force of the machine.

Before taking readings the machine should be run for an hour, or several hours if it is large, so that it may get as hot as it will in practice. As the magnets are wound with copper wire their resistance varies considerably with the temperature. When the machine has been running at full load for some time readings should be taken in two sets. One with the load gradually increasing and one with it decreasing. A machine for incandescent work should be made to compound up to allow for the loss in the leads and for the slower speed of the engine at full load. It may then be tested either at constant electromotive force or at constant speed, or between the two. In practical work it is between the two, but it is generally best to test it at constant electromotive force. If the machine is shunt wound it should be run on open circuit for some time, to see that the shunt does not get too hot. The electromotive force of a slow-speed or badly-designed machine often rises considerably at no load.

A shunt machine wound for charging accumulators with constant current at approximately constant speed cannot be tested as a self-exciting machine without accumulators, as it is unstable; it must, therefore, be separately excited, and its performance can be deduced from the results so obtained.

Immediately after the full load tests the machine should be shut down and the resistances of the different circuits taken hot. These measurements give data for finding the temperature of the armature and field magnets. The hand should not be relied on as a guide, as a bare armature wire at 40° C. will feel hotter to the touch than a cotton-covered unvarnished wire at 50° or 60° C.

Arc light machines, of course, give no special trouble. As far as the machine itself is concerned the curve may be taken accurately between points 15 per cent. on each side of the normal current, and enough data will be obtained.

In many cases there may not be sufficient power available to drive the machine at full load. The machine may then be run slow, so as to give a low electromotive force, the shunt being separately and fully excited. This gives the full torque, and so the armature is subjected to its full driving strain; and the lead of the brushes is also the same as at the higher speed. The compounding test taken at a low speed is, of course, inaccurate, but the exact performance at a high speed can be got by correction from it. If the machine has large armature bars it should also be run at full speed with no load to see if the bars heat from Foucault currents. This also gives an opportunity of seeing how the armature runs as to balance. The method of balancing an armature on knife edges usually employed by dynamo makers does not really ensure balance, as one end may be out of balance on one side and the other on the other, which would not show on the knife edges, but would give trouble in the dynamo.

Many points connected with testing dynamos are here left untouched, because their discussion would lead us into questions of dynamo design and manufacture, which are beyond the scope of this book, The efficiency of dynamos and motors used till lately to be tested by means of dynamometers and brakes. To test a dynamo its power was supplied through a transmission dynamometer, and the out-put was measured by suitable instruments, and the gross efficiency was thus obtained. The drawback to such methods is that few people have dynamometers, and the loss in the conversion of the mechanical into electrical power is too small to be measured by such means; in fact, the errors arising in the dynamometer might easily be greater than the whole loss in conversion.

Such rough methods have been superseded by more simple, and at the same time more scientific means.

Dr. Hopkinson's method is well known, as it has been frequently described. He couples a dynamo and motor together rigidly so that one can turn the other. The motor drives the dynamo through the rigid coupling, and the dynamo gives back most of the power electrically to the motor. The loss in the two machines is supplied by a small belt with a transmission dynamometer. As the power supplied to the system by the belt is only a small fraction of the whole power to be measured, any slight inaccuracy arising from the use of the transmission dynamometer is insignificant in comparison with the power transmitted through the motor shaft. The electrical measurements are, of course, capable of great accuracy.

Shortly after the publication of the tests of the Edison-Hopkinson machines by Dr. Hopkinson's method, the writer discussed with Mr. Crompton several methods of coupling up machines wound in different manners, so that the lost power could be supplied electrically instead of mechanically. This method was brought before the Dynamicables, or mentioned there by Mr. Crompton. Lord Rayleigh almost immediately afterwards proposed to supply the power electrically instead of mechanically.

The publication of the Manchester tests also brought out the information that Captain Cardew used to use a method of testing in which all the measurements are electrical. The dynamo supplies electrical power to a motor, and this power is measured by suitable instruments. The motor then drives a dynamo, and the output of the dynamo is measured. From these data the efficiency of the machines can be calculated.

Various modifications have been proposed, differing chiefly in detail. The drawback to Hopkinson's method is that it is not applicable unless there are two similar machines to be tested, and this is seldom the case; moreover, it would not do well for small machines. Captain Cardew's also demands three machines, of which two must be adaptable as dynamo and motor, and must be large enough to run the other at full load.

The writer has brought out a system in which, besides the machine to be tested, only a comparatively small dynamo is necessary. This system is so much simpler and so much more generally convenient, that it will be fully described without further discussion of the other methods.

There are several distinct sources of loss in dynamos and motors, namely, loss in overcoming the resistance of the wire on the armature and field magnets, loss in mechanical friction in the bearings and against the air, loss by reversal of magnetisation of the armature core, and loss by eddy currents in the armature core, and in the armature conductors in large machines, and in some cases in the field magnets. The loss by resistance of the conductors in a machine can be calculated, and the whole loss in the machine can be also determined; the difference between these gives the loss by friction and by eddy currents and reversal of magnetisation, but as these losses cannot well be separated they may be all treated together and called the stray power.

The stray power is determined by exciting the field magnets so that the armature has the same induction as at full load, the electromotive force on it being such that it goes at its normal speed. The power taken to drive it is equal to the stray power at full load.

Take as an example a shunt-wound dynamo, giving 100 volts and 500 ampères at 950 revolutions per minute. Suppose the shunt resistance is 12 ohms and the armature resistance is ·006. The armature loss is then the square of the armature current multiplied by the resistance, or $(508)^2 \times \cdot006 = 1{,}1548$ watts. The loss in the field is $100 \times 100 \div 12 = 833$. To determine the stray power it is necessary to find the armature electromotive force at full load. As the resistance is ·006 and the current is 508 ampères, the loss is 3; so that the armature electromotive force is 103 volts. The little dynamo must, therefore, be arranged to give 103 volts, and the dynamo to be tested must be run as a motor by it. It will, of course, run at less than 950 revolutions, as the field will be over excited, and there will be no back induction. Resistance is then inserted in the shunt circuit till the speed reaches 950. The electromotive force and current through the armature are then measured, and their product is the stray power. Suppose, for example, that the readings are 103 volts and 9 ampères, the stray power is then 927 watts.

By back induction the writer means the negative induction due to the armature wire, which opposes the induction due to the field circuits, that is to say, the effect of the current in the armature wires included in twice the angle of lead of the brushes.

It is perhaps hardly necessary to say that induction is used in more than one sense, and that back induction has nothing to do with self-induction. There is a popular error to the effect that self-induction is in some way or other a source of loss of power in a dynamo. There is no loss of power by self-induction; from the nature of self-induction such a thing is unthinkable. Self-induction can no more cause a loss of power, or a back electromotive force, than a fly-wheel can absorb power in an engine. Neither is there any lowering of the electromotive force of the machine, or any increase of armature resistance except that due to the heating of the copper.

Taking the loss as 1,548 in the armature, 833 in the fields, and 927 stray power and 50,000 as the output, we get the total power supplied by the belt$=$53,308, so the gross efficiency is 50,000/53,308$=$93·8 per cent. As a dynamo, the electrical efficiency is 50,000/52,381$=$95·5 per cent., and the efficiency of conversion is 52,381/53,303$=$98·3.

To find the efficiency as a motor, we must find what the machine will do as a motor. It may be run with 100 volts on the terminals, in which case it will not run at 950 revolutions, because with 100 volts on the field that gives 103 armature volts, which would take 106 terminal volts. It would therefore run at 895 revolutions with 100 terminal volts. We may, however, assume the same speed, but imagine the shunt wound so as to give the same ampère turns with 106 volts, in which case its resistance and the electromotive force on it are both higher, but the power absorbed is sensibly the same, namely, 833 watts.

We then have also the same loss in the armature, as the armature current will remain 508 ampères, the armature having had that current before. The stray power also remains the same, namely, 927 watts. The motor thus receives $106 \times 508 = 53{,}848$ watts supplied to the armature and 833 to the fields, making 54,781. Of the power given to the armature, the power equal to the product of the current and back electromotive force, viz., $103 \times 508 = 52{,}324$ watts, is converted into mechanical power. Of this 927 is lost as stray power, so 51,397 watts are available on the pulley of the motor.

The conditions as a motor are then 106 volts, 516 amperes, as the shunt still takes practically 8 ampères. The electrical efficiency $= 52{,}324/54{,}781 = 95{\cdot}7$ per cent., the gross efficiency is $51{,}397/54{,}781 = 93{\cdot}7$ per cent., and the efficiency of conversion is $51{,}397/52{,}324 = 98$ per cent. The differences between the efficiencies as a motor and as a dynamo are due merely to the way of taking them. The differences are small in this case because a machine of high efficiency has been taken, but in the case of a small machine the difference would be greater; just as the difference between discount and premium increases with the percentage.

If the machine is compound or series wound, of course it is equally easy to test it. A series wound machine must of course be separately excited for the determination of the stray power.

Compound motors need not be considered, as there is no use in winding such things. The shunt motor if properly designed, and properly wound, runs at practically constant speed, not only with varying load, but with varying electromotive force on the terminals.

The efficiency of conversion really depends very much on the oil used, and is never a fixed quantity that can be accurately determined.

Of course, the efficiency, as well as the output, is not a property inherent in a machine. People often talk of such and such a machine as having an efficiency of 90 per cent., and an output of so many watts, but such expressions are to a great extent meaningless.

A great deal of harm is done by the growing custom of making slow speed dynamos. In some cases saving space is so important a consideration that it overrides any objection there may be to direct driving, but in most cases slow speed dynamos are a great mistake. A machine which will at 1,200 revolutions give 50,000 watts with an electrical efficiency of 94 per cent. loses 5,320 watts. If it is run at 400 revolutions its output is $55{,}320/3 - 5{,}320 = 13{,}120$ watts only; and its efficiency will be only 71 per cent. A slow speed machine for a given out-put is therefore not only larger, but even then has a low efficiency. The loss by using a slow speed machine is very much greater than that of an intermediate shaft, and the first cost is also very much greater. In many cases an intermediate shaft is not needed, even to run the machine at a high speed. It is just as absurd to run a slow speed dynamo as it would be to run a steam engine or gas engine at a third of its normal velocity.

It frequently happens that a machine is built which is so large that the makers have not engine power to run it off. It can then be tested by running it slower, so that the load is less, and separately exciting the shunt, or putting the coils in parallel. The field must, of course, have its normal excitation, and the armature must give its full current, though not its full electromotive force. The position of the brushes is thus found and the absence of sparking noted. The compounding curve can be easily calculated from the curve obtained at the low speed. If there is difficulty in making this test, and other dynamos or storage cells are available to give the normal current of the machine and a few volts, the machine is tested by measuring the torque with the field fully excited and armature held by a lever with a spring balance. Two torque readings should be taken, one when the balance is moved so that the armature turns against the pull, and one in which the armature is allowed to move a little. The error due to friction is thus eliminated. From the torque test the compounding curve can be calculated if the position of the brushes can be calculated or is known. In very large machines of course the position of the brushes is of very great consequence. Motors can be tested in the same way.

CHAPTER IX.

BATTERIES.

Very little need be said about primary batteries, as they have not yet come into commercial use. In testing a primary cell, the electromotive force on open circuit may be taken by means of an ordinary voltmeter wound with low resistance. This does not really test the cell on open circuit, because most commercial voltmeters absorb considerable power, so that the cell is really giving a current of several ampères. If the cell is small, or if a reading with no current is desired, a potentiometer and standard cell with a local circuit may be used. The various ways of comparing the electromotive forces of cells with great accuracy by the Poggendorff method are given in most text books, so it is unnecessary to repeat them.

When the electromotive force on open circuit is known, the cell may be put to work on resistances, the electomotive force and current being noted from time to time. From these measurements it is easy to see whether the cell does all that is claimed for it.

Secondary batteries have to be tested as to rate of discharge, total working capacity, efficiency, and durability.

If a single cell is taken instead of a whole battery, the results may be somewhat misleading unless some care is taken in drawing conclusions. It is best in bringing out a secondary battery to experiment with single cells; but in ordinary practice the engineer has to deal with complete batteries more than with single cells.

Assuming that the battery is fully formed, the first thing is to make sure it is fully charged. It should be charged till there are clouds of little bubbles coming off both plates even with a small charging current. The specific gravity of the acid should be taken. The acid must be stirred up before dipping the hydrometer in, as otherwise stronger acid may be at the bottom. Some prefer to use weak acid with about one part to 10 of water. The writer believes the acid should be as strong as possible without attacking the spongy-lead plate. When a cell is discharged the acid in the interstices is used up, as the external work is due to the formation of sulphate of lead. The more acid there is available in a given small volume of almost enclosed electrolyte, the larger the output will be, if there is plenty of active coating in contact with it.

The recovery of electromotive force on open circuit, or residual charge as it is sometimes called, is no doubt due to the acid diffusing into interstices where the electrolyte has been used up, that is, where only water is left. Strong acid also gives a slightly higher electromotive force than weak, and lessens the tendency to the formation of basic salts. It has also less specific resistance, and therefore lessens the loss both on charging and discharging.

The higher electromotive force needed on charging is sometimes looked upon as spurious back electromotive force. It is probably due to resistance caused by tiny bubbles of oxygen and hydrogen on the surface and in the insterstices, which increase the resistance enormously by diminishing the section of the electrolyte. There is no spurious electromotive force, at least a cell will charge and discharge slowly within a small percentage of the same electromotive force. If the acid is too strong, the spongy-lead plate may decompose the electrolyte, evolving hydrogen and becoming lead sulphate. Sometimes the spongy-lead plate gives off bubbles continuously even when the acid is not very strong. This is probably caused by some impurity setting up local action. Acid of specific gravity 1.275 can generally be used.

Most of the cheap hydrometers are inaccurate, and it is as well to check the instrument before use. The specific gravity of some acid is measured by the hydrometer. A stoppered bottle of one or two pints' capacity is then weighed carefully with an ordinary grocers' scales; it is then filled with water and weighed again, and then with the acid and weighed. In each case the bottle is filled to the mouth, and the stopper is pushed in, so that there is the same quantity of liquid. The weights of the water and of the acid are taken by subtracting the weight of the bottle, and the specific gravity is got by dividing the weight of the acid by that of the water.

The battery may be discharged at the current given by the makers, or at any rate that does not make the electromotive force drop too much. A curve can be made either with constant current or constant resistance. If the cells are in good order the electromotive force will fall suddenly when the cells are discharged. If the curve is round, it shows that some of the cells are losing their electromotive force before the others. Each cell should then be tested with the low resistance voltmeter to see which have given out. If any one has given out because it is insufficiently formed the electromotive force may be even reversed, while if it has given out because it was insufficiently charged it may either give too little electromotive force, or may have an apparent back electromotive force while the current from the other cells is being sent through, this electromotive force disappearing when the discharge is stopped, and being, therefore, merely the electromotive force necessary to overcome the resistance of the cell.

Cells that are bad should be put out of circuit and discharged, so that they may get more thoroughly formed or charged, as the case may be. If this is not attended to the battery will always be kept down to the output of its worst cells.

To find which plate has given out, the writer's method of proof plates is convenient. A little cell consisting of two plates is kept fully charged. Before use it is tested to make sure that it gives full electromotive force. Then the little negative plate is put in the large cell, and the electromotive force between it and the large positive is taken. This tells if the large positive is right. The large negative is then similarly tested with the little positive. The capacity of each plate can similarly be tested with large proof plates.

The spongy lead plate is more often at fault than is generally supposed. This is, no doubt, because lead sulphate is very difficult to reduce, so that bad contacts formed on discharging are not made good on charging. The writer has suggested the use of sodium sulphate to prevent this, and Mr. Starkey, and after him others, have found the method effectual.

CHAPTER X.

ARC LAMPS AND MIRRORS.

There is little in connection with arc lamps that comes strictly under the heading of Electrical Measurement, but there are one or two points which may be discussed even at the risk of a digression.

An arc lamp cannot be considered by itself as an incandescent lamp can, for its action depends not only on its own mechanism but on the working of the dynamo, and most especially on the kind of carbon used. All that is demanded of the mechanism is that it shall keep the arc as steady as possible. With several lamps in series it is easy to make them burn steadily, but with lamps in parallel it is generally necessary to put resistance in series with each. An arc behaves very much as if it were the seat of a back electromotive force. There is no reason to suppose that there is any back electromotive force. As Mr. Harrison has pointed out to the writer, the phenomenon may be explained without any such extravagant assumption by supposing the cross section of the arc, that is of the heated air which forms the conducting passage, to vary as the current. This is a most natural explanation, as the arc certainly appears larger when the current is large, and one would never expect it to be otherwise. If the specific resistance of the heated air remains the same, and the cross section of the conducting part varies as the current, the arc would behave exactly as if it had a constant back electromotive force, and a given electromotive force, such as 50 volts, for instance, would be enough to maintain any current through the arc. In practice, an arc behaves much as if there were a back electromotive force of about 39 volts, and a small constant resistance of about an eighth or a tenth of an ohm. This may be due to the conductivity of the arc not varying exactly as the current. The difficulties in running arc lamps in parallel, or in working search lights without resistance is due to the arc behaving as if it had a back electromotive force, so that a very small difference of electromotive force on the lamp causes a large difference of current. The difficulty is generally increased in search lights by the use of compound dynamos wound for constant electromotive force. The backward main machine would no doubt be much more suitable.

To talk of the candle-power of an arc lamp as a property inherent in it is absurd, as the candle power depends on the carbons used and the current and electromotive force. It is unnecessary to go into the question of the photometry of arc lamps. Whether an arc lamp system is good or not is determined simply by its burning cheap carbons without flickering. Any lamp will burn expensive carbons; what is wanted is to burn the cheapest possible carbons with the best arcs.

PROJECTOR MIRRORS.

A search light consists of a large arc lamp, taking from 20 to 60 ampères, with a mirror arranged to throw as much of the light as possible in a parallel or slightly divergent beam. Search lights are sometimes called holophotes, though the term seems wrongly used, being more applicable to such things as Stevenson's holophote which was specially designed to utilise nearly the whole of the light of a lamp, while in the search light a large portion never reaches the mirror at all. The only form of simple mirror that will reflect the light in a parallel ray is the paraboloid. It would be too expensive to make such mirrors, so they are not used. A spherical mirror acts nearly as well, as the small part of the sphere is nearly coincident with the desired paraboloid. The spheroidal mirror, a spheroid being presumably an ellipsoid, concentrates the light from a luminous point in one focus on another point, known as the conjugate focus. The small part of the spheroid used would very nearly coincide with a spherical mirror. The Mangin mirror is an ingenious makeshift; it is a glass mirror with a silvered back, and both the back and front are parts of spheres, so that the manufacture is easy, but the surfaces are so arranged that the glass corrects the slight error which would arise if a simple spherical mirror were used, and makes the mirror send out the rays parallel, just as if it were paraboloidal.

To test a mirror it is supported at some distance from an arc lamp or other source of light. A small screen, say a disc of white paper two inches in diameter, is held on an adjustable stand, so that it can be moved about till the focus of the mirror is found. When the focus is found the image of the arc should be accurately shown on the disc. The mirror may not be held quite true. To make sure that it is right, care should be taken that the shadow of the disc falls in the centre of the mirror, which can easily be seen, as there is a central hole; and the image should fall in the centre of the disc. The arc lamp must then be in the principal axis of the mirror. If the mirror were truly ellipsoidal, and the lamp were in one focus, the image would be perfectly sharp. If the mirror is spherical, some aberration must be expected. If the arc is at a considerable distance this is a very good test. If the mirror were a paraboloid it would be necessary to use another as well. One mirror would then be arranged with an arc lamp as in a search light, and it would be adjusted to a parallel beam, this beam would then be received by the second mirror, and a perfect image of the arc should be thrown on the little screen.

In testing mirrors by simply using the search light, it must be remembered that the beam which appears parallel to anyone at the lamp really diverges very considerably. A perfect paraboloidal mirror would show a bright spot only 20 inches diameter on a distant object, such as the wall of a house. The whole of the light would, for instance, show only a bright spot in the centre of an ordinary church clock. Mirrors are never so perfect as this, and it would be useless to make them so.

If the mirror were truly ellipsoidal, the light could be converged to a point at one particular distance off. This also would be useless. The advantage in testing the mirror with the little focus screen is that it is easy to secure adjustment.

It has been assumed that a "spheroidal" mirror is ellipsoidal, but the word might also mean "sphere-like." The terminology of these curves is really unsystematic; one would expect an ellipsoid to be a plane curve like an ellipse, not a surface; and if an ellipsoid is described by spinning an ellipse, a "spheroid" would be nonsense, and a cycloid would be a sphere.

CHAPTER XI.

INCANDESCENT LAMPS.

Incandescent lamps have to be tested as to candle-power and as to life. As there are very many popular errors as to incandescent lamps it is advisable to go into the matter somewhat fully.

As a solid opaque body is gradually heated it throws off energy in the form of heat and light. At a low temperature it throws off heat only, but on becoming luminous it gives out red light. As the temperature is increased it adds yellow, and so on, till it gives a complete continuous spectrum, and the intensity of all the different coloured lights increases; but the last added increase fastest. Thus, as the body rises in temperature, the light increases faster than the heat radiation, and the yellow, and finally the blue lights, increase more rapidly than the red—so that the body not only gives more, but whiter light.

When a certain power—say, for instance, 50 watts—is spent in a lamp carbon, the temperature rises until the emission of energy by radiation, and the loss by conduction is equal to the power supplied. If the body is in what practically amounts to a vacuum, so that the loss by conduction or convection may be disregarded, the radiation need alone be taken into account. If the body has a large surface, it will be able to radiate all the power at a comparatively low temperature. The smaller the surface the higher will the temperature be to radiate a given power. Temperature and surface are not the only factors, however; for a piece of black carbon, and a piece of silver of the same size and at the same temperature, would not radiate the same quantity of energy per second—that is to say, they would not get rid of the same amount of heat per second, or give the same light. They would not, therefore, require the same power to keep them at the given temperature.

Though two bodies with the same surface area, but with different emissivities, would not emit the same light or heat, they would emit light of the same colour—that is to say, the proportions of heat and of lights of different colours in the two cases would be the same, though the total emission would be different. The piece of black carbon would thus give more light than the silver, and would also radiate more heat; but the ratios of the ight to the heat in each case would be the same. The power taken to preserve the bodies at the given temperature would therefore be in proportion either to the heat radiated or to the light emitted, or to the light of any one colour emitted —that is to say, they would have the same efficiency as to light given and power absorbed.

We thus arrive at a most important law in the theory of incandescent lamps: namely, that incandescent bodies at the same temperature give light of the same colour, and are at the same efficiency—that is, give the same number of candles per watt.

Mr. Bottomley read a paper at the British Association in 1887, giving an account of some experiments as to colour and temperature. His conclusions are opposed to those generally accepted by physicists, and before they can be accepted a great deal more evidence must be given. Mr. Bottomley, apparently, regards his paper as a mere first notice, and intends to continue his important experiments. At present it may be suggested that his arguments as to Mr. Evans' experiments are open to criticism. The resistance of a lamp carbon varies with the temperature in accordance with no evident law, and the colour of the light and radiation depend on the surface temperature, whereas the resistance depends on the temperature of the whole carbon. A carbon of high emissivity would need a higher internal temperature to preserve a given surface temperature than one of low emissivity. The same reasoning applies to two platinum wires, one of which is blackened. Besides, Mr. Bottomley does not state whether the lamp blacked wire was heated to incandescence before the tube was sealed off the pump; and if it were not, it would be coated with hydro-carbons, which would spoil the vacuum in that tube. It is, no doubt, unlikely that one so careful as Mr. Bottomley would make such mistakes; but, on the other hand, his results are so opposed to those of others, that they must be disregarded for the present, and the law that efficiency is a test of surface temperature, and colour is a test of both, may be taken as true.

Mr. Evans' experiments merely tend to shew that a white carbon has less emissivity than a black one. He took a black carbon and tested it, then made its surface white and tested it again, and found, with the same power, it gave more light than before, and with the same light it took less power than before. He would have got the same result if, instead of lessening the emissivity by whitening the carbon, he had cut a little off the carbon, thus actually lessening the surface. Oddly enough, Mr. Evans supposes the white carbon runs at a high efficiency at a low temperature. In fact, the white carbon is good enough to exercise a sort of selective emissivity. It will, at a given temperature, favour the radiation of light rather than heat. These deductions are quite unwarrantable, as there is nothing in the experiments to support them, and they are opposed to existing knowledge.

It has been so far assumed that none of the power is lost by convection. In a lamp, power is, of course, lost in this way. If it is appreciable, efficiency is obviously no longer a test of temperature; but colour is so still. Convection may be taken as constant, or disregarded, except in the case of a bad vacuum.

As the efficiency depends on the temperature, the aim of a lamp-maker is to produce a carbon that will stand as high a temperature as possible without breaking. Nothing can be gained by using a white surface or a black surface, unless one only exists with a stronger carbon.

The emissivity of the different carbons used by lamp-makers may be taken as the same, provided the surfaces are not very differently flashed; the light of any given lamp then depends simply on the surface area and the temperature, or on the area and the electrical power. Efficiency is not a quality inherent in a lamp. To say that a given lamp has an efficiency of this or that is nonsense; any lamp may be run at any efficiency under its breaking point. If run at a low efficiency it is at a low temperature, and is therefore less likely to break; but it gives less light per watt, and therefore costs more in electrical power. Lamp efficiencies are generally taken backwards. Instead of following the usual practice, and saying, for instance, four watts per candle, the writer prefers to say ·25 candles per watt, or ·25 C.P.W.

The term "candle-power" is also generally used without any definite meaning. A lamp emits more light in some directions than in others. For instance, a thin flat carbon gives very little light edgeways, and a great deal flatways. Its power of illuminating a room depends on the total emission, so that if the emission in one direction were alone taken, it would be no measure of the light given. If the mean of the emissions in every direction could be taken, it would no longer be fair to compare incandescent lamps with gas jets, as the horizontal emission of a gas flame is alone taken. Perhaps, however, a gas flame, being transparent, emits light equally in all directions. To avoid these difficulties the writer always defines the candle-power of a lamp as the emission in a horizontal direction of a cylindrical carbon of the same surface held vertically. This has also the advantage of being almost always easily determined.

This way of taking the candle-power has the advantage of being simple, as most carbons are of circular section and horseshoe, or double-loop form. If a horseshoe carbon is held flatways towards the photometer, it gives out the same light in that direction as it would if it were stretched out into a vertical cylinder. The same holds true with a looped carbon, if the carbon is so thin that the part in front does not sensibly shade a part behind.

It is not necessary to go deeply into the question of photometry of incandescent lamps here, as most engineers do not want to test very large numbers of lamps rapidly, and, at the same time, accurately.

The most convenient form of photometer is the Bunsen grease spot. A block of paraffin with a sheet of tinfoil with a hole in it is preferred by some. Another form is a piece of cardboard with a hole cut star-shaped with a piece of tissue paper pasted on each side. It seems strange that people have devoted so much attention to various forms of photometer and have paid so little to the standards of light.

Candles are not used in practice as light standards. The Methven screen or the Harcourt lamp is convenient. As the writer has had more experience with the Methven screen it will be described. It consists of a Sugg's Referee burner, with a screen between it and the grease spot, the screen being pierced with a small rectangular hole. Photometers with Methven screens are made by Wright, of Westminster. In these the standard burner is on a moving carriage. This arrangement is faulty; the lamp ought to move while the standard remains fixed. The Methven standard is wrong when the screen is close to the grease spot. Before using such a photometer it is

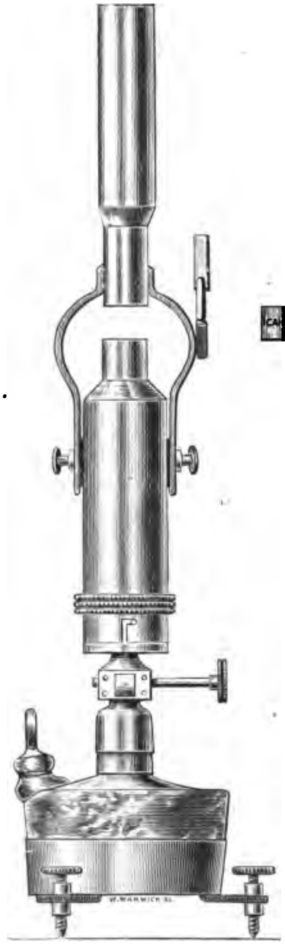

W. WARWICK SC.

Fig. 50.

necessary to calibrate the standard. The first thing to do is to mark off the scale for the lamp. If it is desired to measure lamps up to, say, 50 candles, the far end of the scale is marked 50, and the scale is divided up, the numbers marked varying as the square of the distance from the grease spot. This can be done rapidly with the help of a slide rule.

The pentane, or other standard lamp, is then placed on the mark corresponding to the light it gives. The Harcourt pentane lamp, shewn in fig. 50, is probably far the best and most convenient standard that can be got. The Methven screen is then moved till it exactly balances the standard, and is fixed at that point. If any other standard is at hand, the Referee's burner of the Methven lamp may be used, especially if the photometer is in London, where the gas is very uniform in illuminating power. The screen is removed, and the Sugg burner placed at a distance from the grease spot equal to that of the 16-candle mark on the other scale. The gas is turned up to the right height, and another gas jet of any sort is placed on the other scale, and moved till it balances the standard 16-candle burner. The screen is now replaced, and the burner and screen are moved up till they balance the jet, and fixed there. Of course it is not necessary to make the screen exactly accurate to the Methven sizes if it is calibrated in this way. Any argand burner with a screen of the same sort as Methven's may be used and compared with a standard. These methods of calibration are accurate enough for ordinary work.

In installation work, what is wanted is to be able to run the lamps as bright as possible without breaking them, so that they run at the highest efficiency compatible with economy in replacing. To get the best result it is obviously necessary that all the lamps should run equally bright, that is to say, at the same efficiency and same temperature. To make sure that the lamps all run at the same temperature they should be tested at the same efficiency, that is, the same candles per watt. Thus, unless the efficiency is stated, such an expression as 85 volt lamp means nothing; as a lamp might be run at any electromotive forces from 80 to 90, but would then run at different efficiencies. What are known as high efficiency lamps are simply small lamps tested bright; a similar lamp tested at a low electromotive force would be sold as a low efficiency lamp.

After being sold lamps might be run at electromotive forces different from those marked, and the so-called low efficiency lamp might be run brighter than the other, and would then really give a higher efficiency without getting credit for it. The efficiency is not a property inherent in a lamp, as many people seem to think; it depends only on the temperature at which the lamp happens to be running.

Figure 51 shows a photometer for incandescent lamps designed by the writer. The Methven screen is used, but it is not relied on. The gas burner is fixed, and the scale over which the lamp slides is graduated permanently. The light given by the gas burner is controlled by a slide which alters the size of the hole, and the gas standard is thus calibrated from some accurate standard. The slide is also used to make the necessary corrections when testing lamps with flat carbons, or in testing lamps at efficiencies different with that for which the scale is made out. The scale is graduated so as to do the calculations. A wattmeter is of course better, but there is sometimes difficulty in getting one, as none are made that are suitable for incandescent lamp work. Ayrton and Perry's instruments are shown on the photometer. The writer himself prefers his own skew tangent instruments.

The photometer is, of course, provided with adjustable resistances, such as the mho switches already described; or secondary batteries may be used with switches for varying the number, as described for use in calibrating voltmeters. In incandescent lamp manufacture a wattmeter is used as well as a voltmeter and ammeter, as it saves a great deal of time; but for testing lamps, for instance, at an important central station the work can be done with only a voltmeter and an ammeter. The voltmeter should be put in shunt to the ammeter and lamp, not to the lamp alone, and the ammeter and the leads from it to the lamp should be without appreciable resistance. If their resistance is appreciable, the writer's method of compensation may be used. Part of the current circuit is wound backwards round the voltmeter till there is no deflection when the lamp holder is short circuited, the voltmeter will then read the electromotive force on the lamp, though it is not really on its terminals. A fine wire in shunt to the ammeter is often convenient for winding these backward turns.

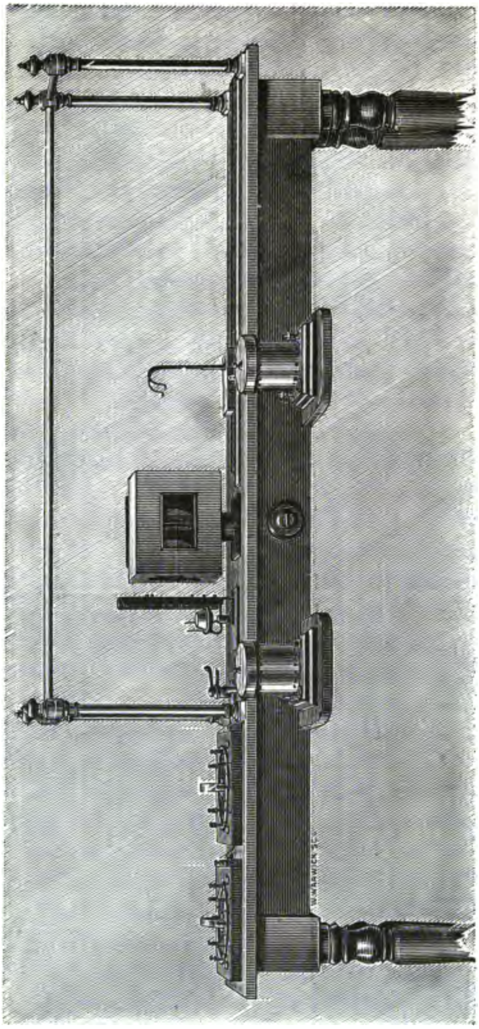

W. WARWICK SC.

Fig. 51.

Before testing a lamp it must be decided what efficiency it is to be tested at. The writer generally takes ·3-C.P.W. as the normal efficiency; some, however, prefer the lower efficiency of ·25-C.P.W., or, taking it backwards, 4 watts per candle. The lamp is put at the expected candle-power, say 16, and run up by the mho switch till it gives 16 candles. The electromotive force and current are taken and their product multiplied by ·3. If this gives 16 candles, the lamp is running at ·3-C.P.W., and may be labelled with the volts and ampères read. If too bright or too dull, a new reading is taken and a new calculation made, and so on. A slide rule is convenient to make these calculations, but even then the process is very slow and tedious. The writer has designed a photometer scale which saves a great deal of labour. The index on the lamp-holder not only passes over the candle-power marks, but stretches across a broad scale. This is marked out with parallel lines running along it marked in volts. Thus for measuring from 40 to 120 volts there are 60 lines marked in volts. The tens and fives are made thick to be more easily seen. Curves, really parabolic, are drawn to represent ampères cutting the volt lines at points such that all the intersections opposite any candle-power correspond to volt and ampère lines whose product is ·3 of the candle-power. Thus, suppose the lamp as before, runs at 16 candles, the voltmeter is read and the ampère line intersecting the corresponding line under the lamp index is noted. Suppose it is 1·4 ampères, if an ammeter shows, say, 1·3 ampères, the lamp is running too bright, and so on. This method, of course, requires no calculations.

Lamps supplied by the makers to run together need not necessarily give the same light or take the same current, but it is absolutely necessary for good work that they take the same electromotive force at the same efficiency, so that they will all run at the same temperature.

If a lamp has a flat carbon a correction must be made. This is done best by opening one lamp and carefully measuring the carbon. The ratio of the surface exposed to the photometer to the surface that would be exposed were the carbon cylindrical is then calculated, and the Methven screen is moved forward a little to make the readings come right. The Methven screen instead of being absolutely fixed is made to move over a short scale. This scale is used for corrections for flat carbons, and for testing at efficiencies other than those for which the other side of the photometer has been graduated. The slide over the slot may be used instead.

The photometer can then be used for testing at any desired efficiency without the calculating scale having to be altered.

Testing lamps to see that they all run at the same temperature is not enough for installation purposes; the engineer also wants to know which lamps are best, that is to say, which lamps will last longest at a given efficiency. People talk of the life of lamps in much the same way as they talk of their efficiency. The life of the lamp obviously depends on the way it is run and of the durability of the carbon. A good lamp on an installation where the electromotive force varies considerably on each side of the normal will not last as long as a bad lamp run on a circuit on which the electromotive force is kept constant.

No incandescent life tests of any value have yet been published. Tables giving lives, taken with considerable care and trouble have appeared, but in all cases there have been slips and omissions that render the data valueless. Sometimes the lamps have been run at different efficiences; mistakes have nearly always been made in taking the candle-power, and the electromotive force has not been kept absolutely constant. We thus do not yet know what is the best efficiency at which to run well-made lamps.

It is not difficult to determine which of two or three types of lamp is the best. If the lamps are for parallel work, as is generally the case, two or more specimens are carefully tested at the same efficiency. If the electromotive forces required are not the same, resistance is put in series with those of low electromotive force till they can all be run together. They are then run in parallel and their lives noted. As this test may take a long time, and it may be inconvenient to get enough electromotive force to overrun them, it is a good plan to order a few lamps of slightly lower electromotive force than those in use on the installation.

In many cases it will be found that instead of breaking a lamp increases in resistance, thus protecting itself. A lamp that has increased in resistance may be regarded as broken, because such lamps are practically useless. If some of the lamps on an installation run dull they are really valueless, as it would pay better to replace them than to continue to run them. If many run dull, however, the chances are that the engineer will increase the electromotive force of the circuit to suit the dull lamps, so that the bright lamps break. If new lamps are ordered to replace those of the original electromotive force, they will be overrun. If lamps are ordered of higher electromotive force, the electromotive force needed on the installation gradually rises till the engine can go no faster. The result is that all the lamps on the installation are run dull, and therefore expensively. This is the reason why the lamps on old installations are generally run so dull; all the bright lamps have died out, and those in use are run yellow.

A lamp that blackens may also be regarded as useless. People do not seem to realise what a little light a blackened lamp gives. It is strange that many engineers will buy what are called high efficiency lamps, and will then run them like hot hair pins, or blacken them till they give out something like two candles, still thinking they are getting high efficiency.

CHAPTER XII.

ALTERNATING CURRENTS.

On coming to this question one feels inclined to copy Charles Lamb and begin this chapter by saying "You cannot measure alternating currents."

Before going farther, a digression may be made upon the way alternating currents are generally discussed. It is usual to assume that the curve of electromotive force of an alternating current machine is a curve of sines, or simple harmonic curve. This is quite unwarrantable. The curve of electromotive force of an alternating current machine may be almost any periodic curve which, when plotted out in the usual way, with the time along the axis of x and the electromotive force along y, will have no part of it at right angles to x. In 1881 Prof. Joubert made some elaborate tests of a Siemens alternating current machine, and found the curve to be approximately a curve of sines. On the strength of this it has been loosely assumed that all alternating current machines give curves of sines. To those who prefer simplicity of mathematical treatment to accuracy, such a temptation is very strong. In dealing with coils or circuits which have co-efficients of induction which are constants, as, for instance, a Siemens voltmeter, the back electromotive force at any instant varies as the rate of increase of the current. Now the rate of increase of the sine of an angle compared with the angle is equal to the cosine of the angle, and the rate of decrease of the cosine of an angle as the angle increases is equal to the sine of the angle. In addition to this it must be remembered that the sine of an angle is numerically equal to the cosine of that angle plus a right angle. It is thus easily seen that those who prefer to make the data fit their mathematics are sorely tempted to treat an alternating current as a curve of sines, and to deal with co-efficients of self and mutual induction where such things cannot well be said to exist. This tendency to assume simple laws so that they admit of mathematical treatment does double harm, because the assumed laws are more or less wrong, and because electricians have a curious respect for mathematics, or rather for mathematical symbols, so that writers who introduce formidable looking expressions are always supposed to be authorities, and empirical laws are accepted and the real laws are not investigated. As an example, one may mention the laws of friction and speed, a question of great importance in shafting; and the laws of the relation of horse-power to speed in steamers. Coming nearer home, we have various assumed laws as to the relation of the light to the power of incandescent lamps, and of the life and the efficiency. Perhaps the best instance is in dynamo construction. Probably nothing has done so much to disseminate ignorance about dynamo machines as the various empirical formulæ which have mostly come to us from Germany.

It is sometimes said that even if the dynamo did not give a curve of sines of its own accord, there were properties in a system of converters which compelled it to do so, something of the nature of harmonic fly-wheels. This conclusion depends on two fallacies. The theory is that if a curve has a number of little ripples these little ripples will be toned down by the self-induction of the circuit, so that they will tend to disappear. Then, as every periodic curve can be split up into sets of curves of sines, it may be looked upon as a curve of sines with ripples, and these ripples will be toned down, leaving a simple curve of sines. The fallacy here consists in treating an irregularity as a ripple and then calling a departure from the curve of sines a ripple. A ripple that converted a well-rounded curve into a serrated one would be toned down, but self-induction would not, so to speak, split up a well-rounded curve into a curve of sines and ripples. The advocates of the curve of sine treatment seem to think there is something constitutional in the periodic curve which makes it divisable into curves of sines, much as a lump of salt can be broken up into cubic crystals, whereas it is merely a mathematical convenience. Similarly a polygon can be split up into a number of triangles, but it is not in any way constituted of triangles. It does not seem to be generally known that a periodic curve can be split up into other series than one of simple curves of sines. The other fallacy lies in assuming that a transformer has a co-efficient of self-induction. If either the primary electromotive force curve or the primary current curve were a simple curve of sines, the secondary curve would depart from the curve of sines. This is because the induction does not vary as the magnetising force. As a matter of fact, the discussion of this question is almost absurd, for the closed circuit transformers now in use modify the curve of the primary electromotive force and current so little that they have practically no influence in making the curves come nearer to or further from curves of sines.

It is also often urged that any periodic function can be represented by a series of simple harmonic functions, by Fourier's theorem. That sounds impressive and convincing, but it does not amount to anything. Unless the curve is known the co-efficients of the separate terms cannot be found, and if they could the terms could not be dealt with separately when dealing with circuits of iron cores.

As already mentioned, different types of machine give different no load curves. A Westinghouse machine gives a saw-tooth curve with the points somewhat rounded over. A machine patented by the writer last year gives a saw-tooth with the points still sharper. In machines with a large air space the rounding over is generally greater, so that the curve somewhat resembles the curve of sines.

In dealing with the full load curve it has sometimes been assumed that the armature electromotive force remains the same and that the terminal electromotive force can be obtained when the armature resistance and co-efficient of self-induction are known. With regard to direct current machines the expression " self-induction of the armature " has already been objected to as meaningless; in alternating current machines the term might be used, but there is no constant co-efficient of self-induction. The assumption that an alternating current armature has a constant co-efficient of self-induction is, of course, convenient for use with the assumed curve of sines. Prof. Joubert treated the armature of the machine he tested as having a co-efficient of self-induction. It may have been that he could not resist the temptation, or it may be that in a Siemens machine of the old type the wires of the armature coils are, comparatively speaking, so far from the iron of the field-magnets that the armature behaves almost as if it were in air and had a co-efficient of self-induction. In discussing alternating currents, however, we must not consider old types of machines. Good as was the Siemens as originally brought out, modern knowledge does not design machines like it. Most machines have iron armature cores now. In some, such as the Westinghouse or Ferranti, there is always an air space, in others the armature cores almost touch the poles in passing.

The curve of sines assumption is useful in connection with such things as dynamometers, as it is often convenient to calculate what the self-induction error of a given coil amounts to. Thus it may be convenient to find out whether the error is 1°/₀ or 10°/₀, but when the power wasted in a transformer is about 2°/₀ of the whole, determinations depending on calculations from such a highly artificial assumption as an "angle of lag" cannot be of any value. The error compared with the whole power measured may not be so very large, but compared with the power wasted it may be enormous. It is much easier to assume the waste of power at once than to assume a curve and carefully calculate what the waste would be if the assumption were good.

A glance at what goes on will show how complicated the action of an alternating current machine is. At one position the armature current tends to increase the total induction through the field-magnets, at another to lessen it. In the intermediate position it is in many cases possible to describe a circuit round the active part of the wire, a small part of this being across two small air spaces and the rest being in unsaturated soft iron. This opposes any change of the current. In addition to these any alteration to the magnetisation of the field is again opposed by Foucault currents. It is incorrect to call all this self-induction and treat it as if it had a constant co-efficient. The curve of the machine also depends on what is going on in the external circuit. If the dynamo is feeding 100 transformers, each at half load with the iron not saturated, the curve will not be the same as when it feeds 50 fully loaded transformers with cores highly saturated at each extreme.

It is questionable whether such terms as self-induction and mutual induction are properly used when there are iron cores, and therefore no constant co-efficients. Unless the induction is split up into magnetising force and magnetisation one cannot well think of self and mutual induction, and it is simpler to neglect the magnetising force and consider the magnetisation increased to make up for it. Instead of varying co-efficients of self and mutual induction, it is much easier to think of varying electromotive forces produced in the circuits. The back electromotive force at any instant can then be called the instantaneous back electromotive force. To talk of the self and mutual induction of the coils of a transformer when there is a closed iron core is very roundabout. Self-induction and mutual induction are also apt to be confused with magnetic induction, especially as they are so often discussed together.

The first thing to consider is what we want to measure. People talk loosely of an alternating electromotive force or current of so many volts or ampères, and sometimes mean one thing, sometimes another, and sometimes nothing. Let us suppose the nature of alternating currents not understood, and imagine an electrician investigating their properties with a view to a system which would admit of his obtaining the information necessary for working an installation by suitable measuring instruments. This method of dealing with the subject was, by-the-way, alluded to by Prof. Ayrton in a discussion at the Physical Society. The first thing the electrician will want to measure is the power. In an ordinary wattmeter the force acting on the moving coil at any instant, or what may be called the instantaneous force, varies as the product of the instantaneous electromotive force and the instantaneous current. So that if the moving coil has too much inertia to vibrate with the varying force the mean force varies as the mean product of the electromotive force and current. A wattmeter, assuming there is no self or mutual induction, therefore measures the power. If the part of the circuit in which the power is measured consists of a resistance which gives no back electromotive force, the current always varies with the electromotive force; but if a back electromotive force existed the current would not vary with the electromotive force, but the wattmeter would at any instant measure the product, and would therefore still read the real power.

Having measured the power, the electrician would attempt to split it into two factors corresponding to electromotive force and current in direct current work. He would first try to measure the mean electromotive force and the mean current, but not only would he find that no known instrument will measure it, but that the measurements would be useless if taken. For instance, to make the case simple, suppose an electromotive force were alternately 2 volts and 4 volts for a second each. The mean electromotive force would be 3 volts. If there were 1 ohm in circuit the current would be alternately 2 ampères and 4 ampères for equal times. When there were 2 ampères and 2 volts the power would be 4 watts, when there were 4 volts and 4 ampères there would be 16 watts. The mean power would therefore be $(16 + 4) \div 2 = 10$ watts, but the mean electromotive force and current would be 3 volts and 3 ampères, their product being 9. As the electrician wants factors of the mean power, the mean electromotive force and current are of no use whatever. If there were a varying back electromotive force, the product of the mean electromotive force and current would be still wider of the mark. As the power varies as the square of the electromotive force and as the square of the current when there is only resistance in circuit, the electrician would turn towards the dynamometer, wound as a voltmeter or ammeter, in which the instantaneous force varies as the square of the instantaneous electromotive force or current, and the mean force varies as the square of the mean electromotive force or current. Such instruments, if graduated to read the force—not the square root of it—would read the power. Thus, if the high resistance dynamometer were in shunt to the resistance, it would read the power, and the low resistance dynamometer, in series with the resistance, would also read the power. In one case the reading, in volts squared, would have to be divided by the resistance, and in the other multiplied by it, to give the power. Still, the readings are not what are wanted, as power varies as the square of electromotive force or of current. If the instruments are now graduated to read the square root of the mean force, the factors desired are obtained. Thus, to find the power spent in overcoming a resistance, the square root of the mean square of the electromotive force is multiplied by the square root of the mean square of the current, and the result is obtained in watts. These factors may be called the virtual electromotive force and virtual current, as the other expression is cumbrous. The name is fitting, because the virtual electromotive force and current are not the real mean electromotive force and current; but they are such, that when working on resistance, the power, $W = \frac{E^2}{R} = C^2 R$, E and C being the virtual electromotive force and virtual current. Thus in the case taken above of 2 and 4 volts on 1 ohm, the voltmeter measures the mean of the two forces, 4 and 16 corresponding to the squares of the instantaneous electromotive forces. This mean is 10, and the dial is graduated to read the root of it. The ammeter similarly reads the root of 10, so that the product is 10, the real power in watts. The power could also have been determined by either instrument alone as the resistance was known.

If, however, there is a varying electromotive force in the circuit as well as a resistance, the product of the virtual electromotive force and virtual current no longer gives the power. For instance, there might be 4 virtual volts when, on account of the back electromotive force there was no current; and there might be 4 virtual ampères later on with no virtual volts, caused by a forward electromotive force. The real power would then be zero, but the mean product of the virtual electromotive force and current would be 8. It is almost needless to remark that with a constant current the virtual and real current or electromotive force are the same.

The electrician has now got something to go upon. In an installation he wants first to know the power given out by his machine. He can get that with a wattmeter. Next he wants to know how that is made up, because a given power might be over-running a few lamps or running a number dull and heating the leads. As already explained, the product of the virtual electromotive force and current does not always give the real power in watts. If transformers are used the error depends very much on their construction. If the current varied with the electromotive force the curves of the current and electromotive force would be similar, and might be plotted out to coincide exactly. This is what happens on resistance. The curves might be exactly similar, but the rise and fall of the current might take place after that of the electromotive force. The curves though similar would then differ in phase, and the product of the virtual electromotive force and current would not give the power. Further, the current curve may be of different form, either retarded or not retarded, when the product of the virtual electromotive force and current will again differ from the real power.

The error due to the difference of form and of phase depends very much on the transformers used and on the dynamo. Thus, in parallel distribution, closed iron circuit transformers cause a very small error compared with open transformers. For instance, imagine a closed circuit transformer with iron so soft that its permeability is infinite, with no persistent magnetism, with wire of no resistance, and with the same number of turns in the primary and secondary. The transformer would then modify the curves in no way, and it would make no difference if it were cut out and the machine coupled direct to the external circuit. If the secondary had more turns its electromotive force would be increased and its current diminished in proportion. Suppose now that the wire has resistance, the effect is then just the same as if the dynamo worked direct on the external circuit with this resistance inserted. The electromotive force and current curves are still similar and the same in phase. Suppose now the iron is not infinitely soft the current curve will be modified in an irregular way, and persistent magnetism and Foucault currents in the core will also modify both the electromotive force and current curves, so that they are no longer similar nor of the same phase. The difference between the product of the virtual readings and the real power may not be great, but its amount depends on the construction of the transformers, and it is beyond the scope of these articles to go into the question of alternating currents generally.

For all practical purposes modern transformers may be treated as if there were no lag, except in taking the loss at no load.

The next thing the engineer in charge of the installation requires to measure is the electromotive force, as far as the question of leakage and breaking down of insulation is concerned. For this purpose very exact measurements are unnecessary. The insulation is, of course, most likely to give way when the electromotive force is highest, so it is not a question of the mean square or virtual electromotive force, but of the highest electromotive force to which the insulation is subjected. This may be taken, roughly, as twenty-five per cent. more than the virtual electromotive force: It does not follow that cable, whose insulation will not permanently resist 1,000 volts from a direct current machine, will break down with 1,000 volts virtual electromotive force from an alternating machine. Insulation seems to break down from some sort of electrolysis, and with an alternating electromotive force it is probable that any harm done when the current is in one direction, is undone again when it is in the other. Leaks can be tested for with an alternating current voltmeter in the same way as in the case of direct currents. As the current through a leak does not vary as the electromotive force on it, this will not give the insulation of the circuit exactly in megohms; but this is a matter of little importance. Practically, all that is wanted is to know if the insulation is good, indifferent, or bad. The current due to the capacity of the system must not be forgotten. The capacity of a system is probably too small to have any appreciable effect. A microfarad condenser takes a large number of plates close together; but if the capacity of a system was one-hundredth of a microfarad, the leakage test would be of no use. The capacity error can be avoided by taking two readings. One of these is taken from one terminal to earth, and another from the other terminal to earth. As the capacities of the sides are probably the same, the reading should be the same, if there is no leak. Such readings should be taken from day to day. If there is a leak the readings are modified. On one side the instrument is in shunt to the leak, and on the other in series with it, so that a rough idea of its magnitude can be got.

The product of the virtual current by the resistance of the lead gives the power spent on it as resistance. To find the loss of power in leads this is not enough, as the electricity streams in the lead act on one another when the current varies, and this makes the lead act as if it had extra resistance. This apparent resistance varies and depends on the current, and on its rate of increase and decrease, or, in other words, on the current curve. This can be tested by taking the power by means of a wattmeter. The lead has self-induction proper, which gives an instantaneous electromotive force, and may be considered as due to the change of stress outside the wire, and it has this internal mutual induction of the current in every part of the cross section on every other part. The self-induction proper, due to the external stress, causes a varying opposing electromotive force, in overcoming which energy is merely stored. The internal interference with the distribution of the current causes loss of energy in heating. The wattmeter, of course, measures this loss of energy; but, as already explained, no error is caused by the self-induction proper. The waste of power by the mutual induction of the electricity streams is perhaps more important than generally supposed. The simplest way to avoid it is to use cables which are made up of strands, which are themselves made of several wires twisted together. A cable made of several solid wires twisted together, such as those generally used in direct current work, does not get over the difficulty. The twisted cable should have no core—that is to say, seven little cables should not be twisted together with one of them in the middle, but six should be twisted round a rope, or other idle core. In testing for loss of power in leads, the lead must not be coiled up; it must be well opened out.

There are only a few instruments available for the measurement of alternating currents, because, as already explained, the engineer wants to measure the power, and the virtual electromotive force and current. The only instruments in use that will do this are the various forms of Weber's dynamometer, electrometers of various kinds, and Cardew's voltmeter. The various instruments with magnetised needles are not deflected, or are, at most, deflected by Foucault currents in the needles. Instruments with wrought iron in them, again, do not measure anything in particular. In America, instruments in which a soft iron core is attracted into a solenoid are largely used for alternating current work; but these really do not measure. The deflection of the index has no definite relation to the virtual current through the instrument. If the iron were very small, so that it became saturated at once, such an instrument would measure something approaching the mean current through it, which would not be of any use; but even then the error due to the self-induction of the coil, and to the back electromotive force due to the magnetisation and demagnetisation of the iron core, interferes with the action of the instruments.

Probably the only accurate instrument is the electrometer. This can be used for measuring virtual electromotive force, and can be made to measure current by coupling it in shunt to a known non-inductive resistance. Profs. Ayrton and Perry have also pointed out that it can be arranged as a wattmeter. It is specially applicable for measuring high electromotive forces, as it takes no current; and as the force on the needle varies as the square of the difference of potential, it is then large enough to make a sensitive instrument. If the ordinary Thomson electrometer is used, care must be taken that the needle is set so that there is no force acting vertically on it, otherwise an error will be introduced, as pointed out by Dr. Hopkinson. The terminals should be connected with the leads through some high resistance or fuse, so that if the needle accidentally touches, no harm may be done. A wet string is a doubtful resistance. It may be so great, that the electrometer, which is a kind of condenser, has not time to charge. This will introduce an error like that due to self-induction in dynamometers. It is also possible that the wet string acts like an electrolyte and polarises, in which case there might be an error of about a volt in the virtual electromotive force.

Sir William Thomson has lately brought out a simple form of gravity electrometer, which is much more suitable for engineering work than the laboratory form.

This is shown in figure 52. It consists of a movable needle very carefully pivoted, and a pair of fixed plates. The needle is attracted by the fixed plates and the attraction is opposed by the force of gravity. Such an instrument should, therefore, never need calibration. Of course it is not meant to be very portable.

Mr. Wright's electrometer has also been mentioned in connection with high-tension direct currents.

For measuring current and power the electrometer is not so good. For measuring current, the resistance in shunt to the electrometer must be large enough to give something like 100 virtual volts, otherwise the instrument is not sufficiently sensitive to read well. The same difficulty occurs with a quadrant electrometer arranged as a wattmeter. A two-plate electrometer, such as Sir William Thomson's electrostatic voltmeter, cannot, of course, be arranged to measure power.

The simplest way to measure power by means of an electrometer is to put a non-inductive resistance in series with the circuit in which the power is to be measured. The needle and one quadrant are connected to the ends of the circuit and the other end of the non-inductive resistance. The difference of potential between the needle and one quadrant then varies as the instantaneous electromotive force, and the difference of potential between the two quadrants as the current, so that the instantaneous force varies as the instantaneous power, and so the instrument reads the mean watts. This is only accurate, however, if the fall of potential over the non-inductive resistance is inappreciable compared with that over the circuit. The reading is really proportional to the power spent in the circuit added to half

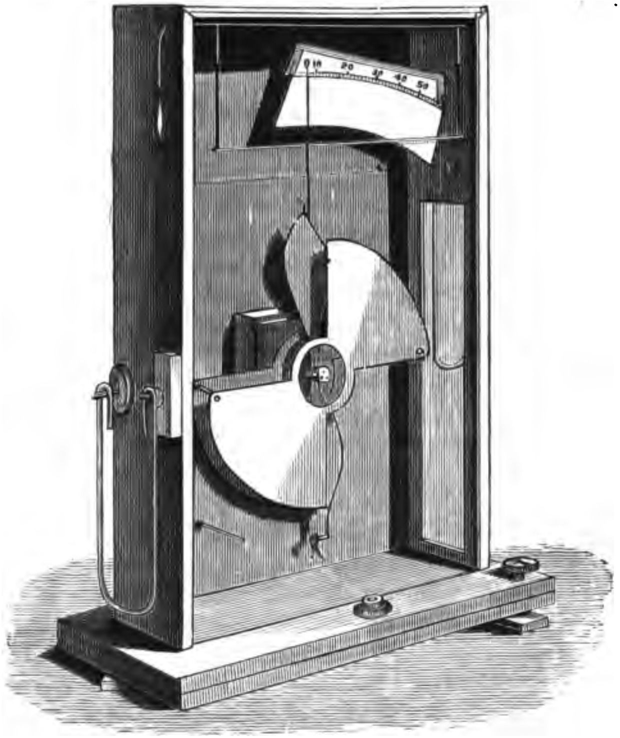


FIG. 52.

that wasted in the non-inductive resistance. The correction for this can be made if a dynamometer reading the virtual current is in circuit. Professors Ayrton and Perry have introduced another method. They couple the quadrants in shunt to the circuit, and the needle and one quadrant in shunt to the non-inductive resistance and take a reading. The needle connection is then moved so that the instrument is in shunt to the circuit only, and the difference between the readings thus obtained gives the true power without further correction. This demands two readings but only one instrument.

Quadrant electrometers are not suitable for ordinary work, because they are delicate laboratory instruments, and are not direct reading.

Of the dynamometer the Siemens form is the best known. It has the grave disadvantage of not being direct reading. The fault generally found with such instruments is that there is an error from self-induction. This is true, and with a rapidly alternating current the error may be very great. Apparently, no trouble has been taken to avoid such errors. There is no reason why a dynamometer-voltmeter should not be so designed that there is no perceptible error with 10 to 15,000 alternations per minute. Such an instrument is, of course, delicate, as the force acting is small, and so the spring has to be made weak. Still, it is much better to make a dynamometer with a weak spring, than to have recourse to such a troublesome instrument as a quadrant electrometer, or to a calorimeter. The amount of the error due to self-induction varies with the curve of the electromotive force, and, of course, with the speed of the engine or number of alternations per minute. The error from self-induction depends on the figure of the coils, not on the number of turns. Thus, if a dynamometer wound for 100 virtual volts were re-wound to give the same reading with 50 virtual volts, the percentage error would be the same as before. The self-induction error may always be reduced by using a comparatively low resistance voltmeter, and arranging a non-inductive resistance in series with it. Changing a German silver or platinoid coil into a copper one with the same number of turns and putting an external resistance in series, as is frequently done in direct current work, will not overcome the self-induction error, because the coil has the same shape and same ampère turns as before.

As already explained, however, very accurate determinations of the virtual electromotive force are of no real use in practical work. On an installation the best method is to have a photometer, and to run a lamp at the right temperature and efficiency first with a direct current, or with an alternating current and a wattmeter, and to note the virtual electromotive force on a dynamometer-voltmeter. Afterwards, it can always be seen when the lamps are bright enough, by this calibrated instrument.

At a central station the man in charge of the engine has generally to look after the primary circuits ; if he has any lamps on a transformer he can keep them right and let the primary circuit take care of itself. A little transformer is sometimes used, so that a low resistance voltmeter can be used ; a suggestion made by Mr. Rankin Kennedy. It is better to put the voltmeter on one of the transformers of the usual size, however, as the indications of a special little transformer might be misleading. Besides, transformers do not really regulate perfectly, and as more lights are put on in the various houses the exciting currents have to be increased.

The wattmeter, as already explained, is the only instrument that gives any really exact information in alternating current work. It is, therefore, important that it should be as free from errors as possible. Self-induction errors can easily be avoided in such an instrument as Siemens' ; all that is necessary is to make the current coil give a very strong field, so that the electromotive force coil may have very few turns, and may have these arranged so as to have no appreciable self-induction. There is also no mutual induction between the coils, so that the variation of current in the current coil does not affect the current in the electromotive force coil. There may be small errors in wattmeters for very large currents arising from the distribution of the current in the large wire or rod forming the current coil. The distribution is affected not only by the mutual induction of the electricity streams, but slightly also by the electromotive force coil.

For measuring virtual currents a dynamometer is of course accurate except when errors arise from the cause just mentioned.

Sir William Thomson's current weighing instruments have already been fully described. For measuring virtual electromotive forces the instruments are very convenient, and no doubt the self-induction can be made inappreciable.

Mr. T. Gray has pointed out that the self-induction error can be practically avoided in an instrument with the same number of fixed as of movable coils. The coils are wound so as to repel each other, and are formed so that the mutual induction is as nearly as possible equal to the self-induction of each coil. The instrument then resembles a resistance coil which consists of a looped circuit, so that there is no self-induction. By this means the self-induction error in the alterate current voltmeter can be made negligible.

As wattmeters, those with one stationary coil have the objection that there is mutual induction between the coils, so that the current in the electromotive force coil is affected by the current in the current coil. Sir William Thomson does not, however, describe the instrument wound as a wattmeter.

For measuring virtual currents the inventor winds the coils of cable. The use of cable prevents the current distributions from being altered by the mutual induction of the coils.

Dr. Fleming and Mr. Gimingham's instrument, recently described at the Society of the Telegraph Engineers, is not intended for alternating currents, but there is no reason why it should not do just as well as other instruments.

Direct-reading instruments have some disadvantage in alternating work, as the co-efficient of mutual induction between the coils varies with the position of the moving coil. In a voltmeter with a weak spring and no appreciable self-induction, the mutual induction is inappreciable, too, because it must be less than the self-induction; but in a wattmeter, with a powerful current coil, there may be a small error.

Perhaps voltmeters could be made more dead-beat by coupling the coils in parallel, so that the motion of the coil slightly alters the currents, causing them to oppose the movement. Of course this demands a large fixed and a small moving coil.

Similarly the vibrations of a voltmeter may be damped by a permanent magnet close to, or embracing, a moving part.

Professors Ayrton and Perry's new form of voltmeter is shown in figure 53. It is made on the hot-wire principle, like Captain Cardew's instrument. The wire is mounted so that it sags, one of Ayrton and Perry's springs pulling it gently sideways. As the temperature of the wire rises the sag increases so that the spring attracts and thus works the index. The instrument is thus frictionless, and is very portable. In fact, there are no moving parts in the ordinary acceptance of the term. To get a long enough wire to take, say, 100 volts into the instrument, it is arranged in a sort of star, so that the spring is actuated by the alteration of the sag of all the parts of the wire. The wire is thus somewhat in the form of the spokes of a bicycle wheel, except that the spokes are the other way out. If the sag increases the centres thus come closer together. To make this instrument accurate, it must be compensated for both the temperature errors, as explained in discussing the Cardew voltmeter. For measuring low electromotive force, the inventors arrange a switch which puts all the spokes of the wheel in parallel or series as required.

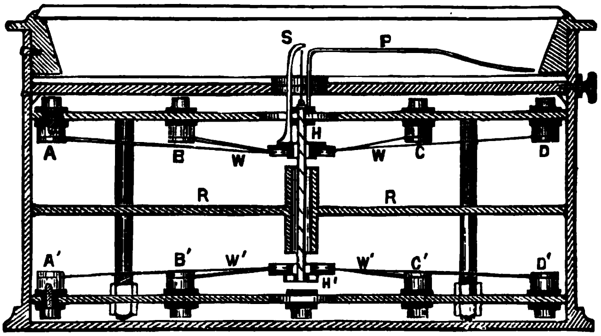


FIG. 53.

The Cardew voltmeter is generally supposed to measure virtual electromotive force accurately. Whether it does so or not is, however, uncertain. Its self-induction is not appreciable. The writer has roughly calculated the error due to this cause in an instrument with wire of ·0025 inch diameter and 12 feet long, doubled into three feet, the wires being a centimeter apart. With 400 alternations per second, it came to one-tenth per cent.

It does not follow that there are not other errors due to the wire rapidly heating and cooling instead of radiating and giving up its heat at a constant surface temperature. In addition to this the current distribution may not be the same as with direct currents. But as very accurate determinations of virtual electromotive force are not necessary, the Cardew is as good, if not better, than any other instrument. The same remarks apply to the new voltmeter devised by Profs. Ayrton and Perry.

The meters of Profs. Ayrton and Perry are suitable for alternating currents. The same precaution must be taken as to self-induction as with wattmeters. Mr. Ferranti has also modified his meter to make it work with alternating currents. Such an adaptation can only be made by long and laborious experiment, and even then it is doubtful if such an instrument can be made as accurate as for direct currents.

Professor Forbes's meter will also do as well for alternating as direct currents. For very large currents the coil must be made of a rope of twisted strands.

Dynamos.

An alternating current dynamo cannot be very accurately tested by the writer's method described in connection with direct current machines, because there are losses of power that do not exist in direct current machines. The changes of value of the armature current produce losses by Foucault currents in the pole pieces, and perhaps in the armature hub also. If these losses are known to be small, the writer's method may be used. The machine to be tested and another like it, or giving a similar curve are run at approximately the same speed, and are then coupled together through a resistance which is great enough to prevent danger if the machines do not run together properly. the belt is then thrown off the machine to be tested, so that it runs as a motor. If there is difficulty in getting the two machines to synchronise, a coil with a little iron core, or something with self introduction, may be put in circuit. Iron-wire resistance may do.

The power taken to drive the machine is taken with a wattmeter. From this is subtracted the power spent on the armature resistance, which is got by multiplying the armature resistance, by the virtual current. In a direct current motor running loose this loss is so small that it may generally be neglected. This is not necessarily the case with an alternating current machine.

Having thus found the stray power, the efficiency is obtained by dividing the output in watts by the sum of the output, stray power, and loss by armature resistance at full load. The exciting power ought also to be included.

Dr. Hopkinson's method might be applied to alternating current machines. Two of these are coupled rigidly so that one opposes the other, and the field of the motor is weakened. The balance of power is supplied by a small direct current motor. The dynamo behaves very much as if it were working on closed circuit transformers. A wattmeter is used to measure the power transmitted by the dynamo. The stray power is divided between the two machines, as in the case of direct currents.

Captain Cardew's method cannot be applied to three alternating current dynamos; but a direct current motor, whose efficiency is known, may be used to drive an alternating current dynamo. The alternating current dynamo may then be connected up and tested, doing its ordinary work.

It may be desirable to find the curve of electromotive force and current of a machine. These can be taken by an electrometer. A contact is fixed to the axle and touches a stationary contact. The stationary contact can be fixed at positions corresponding to different fractions of a period. This contact arrangement, described by Mouton, was used by Joubert, but he discarded the use of the electrometer because he found it difficult to make it work. He had two instantaneous contacts on the axle; it is difficult to see why one would not have done. By moving the adjustable contact into different positions a series of readings can be taken, from which the actual curve can be plotted. A galvanometer must not be used instead of an electrometer.

The current curve can be taken in shunt to a known non-inductive resistance. The needle may then be charged by a multiplier or set of cells.

The curves from transformers can thus be taken also and compared with the dynamo curves.

Prof. Joubert preferred another arrangement. He coupled up a Poggendorff arrangement as if he was going to measure a direct current; but put the contact-maker in the galvanometer circuit. This is perhaps the most practical arrangement. Of course it can also be applied to taking current curves.

Prof. E. Thomson has brought out a very ingenious instrument, figures 54 and 55.

The soft iron core is polarised by the direct current and attracts a diaphragm as in a telephone. A second coil round the core connected with the alternating current circuit to be examined weakens and strengthens the action of the direct current alternately. The diaphragm is connected with a little mirror, so that when stationary a spot light is shown, and when vibrated a line of light appears on the screen. The connections between the diaphragm and the mirror are made by light levers. There are no pinned joints, a piece of metal filed down into a light spring at the bend where flexibility is needed being used. The mirror is hung in little gimbals, and is also acted on by another diaphragm like the first, arranged so as to make its line of light at right angles to the first. On

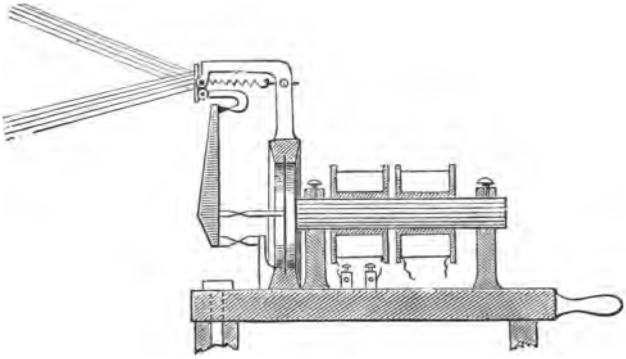


Fig. 54.

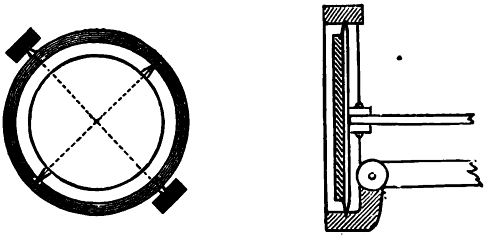


Fig. 55.

looking at the bright spot on the screen, or as it appears reflected in the mirror a line or closed curve is seen. In fact, curves like Lissajous' figures are depicted. This instrument is exceedingly ingenious, like all Professor Thomson's inventions, but, unlike them, it is to be feared that it is not of great utility. The diaphragms and connections must have some inertia which must interfere with the accuracy, especially when there are two or three thousand alternations per minute. The angle the mirror turns through cannot be directly proportional to the current in the alternating coil. It will also be difficult to prevent perceptible retardation of the current round a soft iron core, even if the angle of deflection were proportional to the instantaneous current.

Any two similar current curves of the same phase will give a straight line; and if the phases differ very slightly the curve will be too narrow for its components to be determined. In fact, unless one curve is known it is impossible to find the other.

The writer has designed an instrument for automatically drawing the curves, but as it has not been tried yet its description may be postponed.

The speeds of alternating current machines can be taken by means of a pitch-pipe. An ordinary tuning-fork or pitch-reed will do if the user has an ear sufficiently cultivated to tell the pitch of a note which does not belong to the same scale. If not, a pitch-pipe may be graduated to read very exactly. It must be remembered that pitch-pipes and reeds have temperature errors. A reed expands and gets flatter when warmed ; a flue-pipe or whistle gets sharper when fed with hot air, such as the breath.

Motors.

The testing of alternating current motors might well be deferred till there are some to test.

It seems generally to be assumed that the only difficulty with alternating current motors is to start them. It seems probable, however, that there will be very great difficulty in designing a motor which will work with reasonable efficiency, and varying load. An alternating is a widely different thing from a direct current motor. Take the case of two similar machines driven by belts and coupled in parallel. Imagine first that they have no self-induction, so that the current at any instant is equal to the algebraical sum of the instantaneous electromotive forces divided by the sum of the armature resistances. Such machines would have no tendency to synchronise. If in phase the opposing electromotive forces would neutralise each other at every instant. If they got gradually out of phase an alternating current would be set up and power would be spent on the armature resistances. The machines would contribute equally to this waste. As the machines differed further, the waste would increase until when they were half a period wrong they would both be short-circuited completely.

But if the machines have self-induction, as soon as one machine is ahead of the other and waste begins, the current curve is retarded, and this makes the leading machine do the larger share of work. The self-induction may be large enough to make the leading machine do most of the work and supply the trailing machine with more power than it wastes. The trailing machine is then a motor. Thus a dynamo and motor with no self-induction would not synchronise in parallel; and it is questionable whether machines can be so designed as to electromotive force and current curves as to give a reasonable efficiency with a varying load.

A motor can be run on a series circuit, and will then be efficient at full load; at no load the current remaining the same, of course the loss by armature resistance is not reduced. The machine does not run away as a direct current motor does, it goes on at the same speed. If overloaded, it simply stops. Unfortunately, there is little chance of series systems coming into commercial use. The efficiency of a series motor can be taken, as in the case of a dynamo. The motor described in the Hopkinson test just mentioned behaves as if it were in a series circuit at full load. Such a test must not be used to get the efficiency on parallel circuits. A wattmeter will take the power given to a motor, and if at any instant the motor acts as a dynamo, the instrument will deduct the power, so that it reads only the power absorbed. An alternating current motor can be put to run a direct current dynamo of known efficiency, so that its efficiency can be determined.

Transformers.

The obvious way to test a transformer is to measure the power supplied by means of a wattmeter, and the power given out, and to divide one by the other. The chief difficulty lies in the high electromotive force of the primary circuit. This may be dealt with by Mr. Kennedy's method of using another transformer whose primary is connected to the high electromotive force and the secondary to the pressure coil of the wattmeter. The transformer used for this must have a closed iron circuit, and the secondary should supply very little current. The method is then accurate enough.

If the same wattmeter is used to measure both the secondary and primary powers, or, at least, if the same pressure coil is used, the self-induction error cancels out. This is important, because a very small error in reading makes a large error in the loss of power. A good closed circuit transformer, with a rapidly alternating current, should give about 98 per cent., so that an error of one per cent. in reading may halve the apparent loss of power.

A good closed circuit transformer has not only a high efficiency, but, on resistance, the curves of electromotive force and current in the primary and secondary are almost exactly the same in form and phase. It may then be safe to multiply the virtual electromotive force and current to get the power. In testing the transformer on either arc or incandescent lamp circuits the wattmeter is safest. If tested on resistance without a wattmeter, the wire must be arranged to have no self-induction, and, of course, iron must not be used. On resistance a Cardew voltmeter and a current dynamometer might be used, but it is safer to adhere to the wattmeter.

A closed circuit transformer can also be tested with comparative accuracy by simply putting an alternating electromotive force on one circuit. Thus the secondary circuit can be connected to the secondary of another transformer, so that low electromotive forces are dealt with. The power absorbed is measured. It will, of course, be small. This is the stray power. If the output is known, the loss by resistance in the secondary is taken; the loss by resistance in the primary is then calculated, allowing enough additional virtual current to give the stray power when multiplied by the virtual electromotive force. The three losses are added together and make the total loss, from which the efficiency is determined.

In measuring open iron circuit transformers the wattmeter method is the simplest and best on both circuits. These need not be fully discussed, as they are practically obsolete. The product of the virtual E.M.F. and current must never be taken on the primary circuit.

Incandescent Lamps.

As already mentioned, incandescent lamps do not behave like simple resistance, and they do not behave like resistance and self-induction; in fact, they have a kind of way of behaving of their own. A thin carbon appears to follow the current or power spent, by rapidly heating and cooling. The instant of highest temperature is after that of maximum power. If the resistance remained constant, this rise and fall of temperature would not interfere with the curves of the currents and electromotive forces. If it alters in resistance, as it does if it is not exactly at its points of minimum resistance, the curves are interfered with.

In addition to this, carbon is a bad conductor of heat, so that a carbon is generally hotter in the centre than outside. This alters the current distribution to some extent.

The effect of flickering on a lamp is to make it give a higher candle-power with an alternating current when taking the same electrical power as with a direct current. This is because the efficiency increases more rapidly than the power, so that when very bright the candle-power is much greater than the normal, and when dull it is not much less. As the breaking is most likely determined by the highest temperatures, not by the mean temperature, the lamp to last long must be run duller, till its maximum brightness is only equal to the normal brightness with a direct current. The mean light is then less than before, and the power taken is decreased, though not so much, so that on an alternating current a lamp should really be run to give less light than on a direct current, and at a lower efficiency, though with the same power it would have given more light. In practice, a lamp may be tested on the photometer to give about its normal light, and then run under similar conditions.

At first sight it might appear that a Cardew voltmeter would flicker, and would therefore have the same sort of variation as a lamp. But the flickering tends to make a Cardew instrument read lower, not higher, so on this account it is less suitable. The flickering effect is probably very small, however, especially with a thick wire and rapid alternations.

The theory of incandescent lamps flickering on alternating current circuits has been severely criticised by Professors Ayrton and Perry and Captain Cardew. Professors Ayrton and Perry have made experiments on the subject which tend to show that there is no appreciable difference in the behaviour of a lamp on an alternating current in this respect. As the writer intends to say more on this subject later, the text is not altered.

Arc Lamps.

With direct currents arc lamps are treated as if they had a back electromotive force and a resistance. This is a convenient way of looking at it for direct current work, but it is much more likely that the resistance varies, and that there is no appreciable back E.M.F. If the cross-section of the conducting heated air varies as the current, the resistance varies inversely as the current, and there would be an apparent back electromotive force. If this, or something like it, takes place, the arc would behave in much the same way on an alternating current. The virtual electromotive force might be kept nearly constant and the virtual current might vary, just as the electromotive force and current vary in direct current work. But if the arc has time to cool and increase in resistance between each alternation, the question becomes much more complicated. Most likely it cools too little to make very much difference. The writer does not know of any experiments on these points. The question might be very easily settled.

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